PDHonline Course G295 (15 PDH)

Aero Navigation - Part 1 Through 9 of 35

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Aero Navigation

Part 1 Through 9 of 35

1. Course Summary:

This Aero Navigation system provides an Engineering perspective on 35 different Aero Navigation systems, including 3 Navigation Systems that are not actually used in aircraft. Most pilots are familiar with only 4 Aero Nav systems, & few military or professional pilots have heard of 10.

This course includes three "truly revolutionary" new Aero Navigation systems that are still under development & implementation, & will very soon revolutionize many types of flying; especially instrument approaches. Only a handful of pilots have heard of these as of late 2009.

Few avocations or hobbies draw upon Engineering as strongly as Aero Navigation, which is like much of Engineering in that no 2 flights (projects) are exactly the same, & most are a challenge.

Much of the theory & application of Aero Nav systems are truly fascinating; especially to Engineers. The complexity & ingenuity of Aero Nav systems appeal to most Engineers. The same applies to the applicable tools & instruments that were developed.

Some of the information covered in this Aero Navigation course could literally save a person's life, even if he is not a pilot. It gives extensive ancillary information pertinent to Aero Navigation, & its relationship to flying.

Unsigned words of wisdom found on the internet: Remember that the science of Navigation can be taught, but the art of Navigation must be developed from experience.

This introduction contains a wealth of preliminary, background, & ancillary info that is necessary for the understanding of all 35 Aero Navigation systems in this series. It also discusses 9 of the 35 Aero Nav systems that are included in this Aero Nav series. It includes theory & method of operation, design details of tools, electronics, & instruments required, application, capability, accuracy, limitations, the actions required to use the system, & illustrations of the necessary equipment. It includes early Aero Navigation systems as well as evolution to the current state-of-the-art systems. It does not always provide enough operational detail for navigation. Although it is not essential that a pilot understand all theory in order to navigate a plane, it behooves him to understand more than the minimum required to navigate. Most Engineers would certainly be curious enough to desire to understand background & theory.

The introduction starts with a surprisingly accurate primitive overland navigation system that was never adapted to Aero Navigation. The introduction also includes Dead Reckoning, which is essential for preflighting all flights, regardless of the Aero Nav system used. It is equally important to most other Aero Nav systems. DR is also an important stand-alone Aero Nav system. Likewise, Map Reading is necessary to support most other Aero Nav systems, & is also an independent Aero Nav system. The visible tower airway system quickly evolved from the 1920s to an Aero Nav system that was very valuable until the mid 1950s. It formed the basis of the current airway system. The Sun line concept was discovered in 1837, & improved long before it became evident there was a need for Aero Nav. It is still an excellent emergency nav system for long range overwater flights. The Sextant was developed centuries ago by use of sticks & strings, & became a sophisticated instrument that is used in conjunction with a large set of tabular data, in lieu of complex spherical geometry computations. It was later adapted to an extremely precise Celestial Aero Nav system that is still considered an essential asset of the U.S. navy fleet. This latter system is described as Aero Nav system No. 22 in this course.

Aero Nav is used to predict the distance, time & heading to travel between 2 points on the earth, as well as to establish fixes (intermediate points along the route) as a flight progresses. As important as speed & time are, the heading he must fly to arrive at the destination is also important. These require determination of the optimum altitude, course along the ground, heading of aircraft, location of refueling stops, & "winds aloft" [wind velocity (speed & direction) at several altitudes]. It is also important to establish these values during the preflight planning stage, including intended refueling stops, & ETA (estimated time of arrival) at each pertinent point along the route, as well as to the destination per se.

Each Aero Nav system has its own unique features, complexities, & weaknesses. Each is fascinating in its own way. Most are supported by tools that were developed for that particular Aero Nav system. Each has been very valuable at times during the brief history of aviation; most retain their usefulness 5 to 9 decades after their introduction. Like Engineering, there is a vast difference in accuracies of different means of measuring; be it microinches or miles. For Aero

Nav a 1 mile error is normally minor; sometimes even 10 miles. But on an instrument approach, the error must be less than 100' (how? See Instrument Approach Aero Nav system; No. 30).

The number of Systems is somewhat nebulous. Some might argue that some of these Systems should be combined with another because of their interdependence, or even similarity. Conversely others might say that the E-6B, Weems Plotter, Airplot, autopilot, & several others should be discussed as standalone Systems as opposed to being included with other Systems.

2. Table of Contents

Appendices:

3. General Background of Aero Navigation:

Aero Navigation is more elaborate & complex than navigating a car; or even a boat. It requires a working knowledge of at least a few Aero Navigation systems, specifications & flight characteristics of the plane to be flown, & sufficient knowledge of the atmosphere to safely accomplish a flight.

Maps & charts are likewise important to all Aero Navigation systems; "current" charts are mandated by the FAA. Understanding the magnetic influences of the earth & aircraft are also essential.

Discussion of the safety, practicality, cost, complexity, regulations, licensing, & the variety of options available to the Aero Navigator.

Note: Appendix A lists the pertinent "definitions" of terms & acronyms used in the entire Aero Navigation series.
Other Appendices are used to expound upon the general content of various sections within the course & to provide more detailed "support" type info; both relevant & potentially useful background information.

Note that the author uses the male gender (as in mankind), instead of the generic, as a matter of convenience. He is certainly familiar with the fact that many women are also pilots. In fact, his wife, & several of his female acquaintances are accomplished pilots & Aero Navigators. Two are airline captains; 1 of whom has also held various titles, including world aerobatic champ, for most of the past 18 years. Certainly Amelia Earhart is one of the more famous aviators in the world, but there have been many.

3.1 General Info on Aero Navigation & Aviation in the U.S.:

3.1.1. History & Application:

From the Wright brothers, soon after their 1st flight, to the simple but wonderful ever popular little Piper J-3 Cub that was a popular 1950's trainer, to the most popular warplane of all times (the P-51 Mustang), to the safest, most popular & numerous lightplane ever produced (the Cessna 172), to the current jet fighters & airliners; Aerial Navigation has always been a "necessary evil", a "challenge", or "just another enjoyable part of flying", depending on the "pilot's point of view". Regardless of which of these a pilot considers it to be, Aero Navigation is certainly a challenge; vital & rewarding.

Some of these Aero Nav systems had their origin hundreds of years ago. Some are undergoing development as of 2010. Some earlier instruments were nearly as crude as the bamboo bomb sight used by the Japanese during WWII. Some are even more sophisticated than the phenomenal top secret WWII Norton bomb sight that was developed by the U.S. An Engineer who had been a B-17 pilot during WWII told the author that his bombardier could easily hit a 20 ft square target from 20,000' in smooth air during training with the Norton bomb sight.

Time to the Aero Navigator is more complex & critical than in most activities. See paragraphs 4 & 5; also Appendix D.d for additional information on time.

Navigation tools are discussed here to eliminate the need for repetition in succeeding systems. Dead reckoning, for example, uses basic computational methods that are important to all Aero Navigation systems.

Navigation generally requires 1 or more Navigation Aids. Navigation Aids are Aero Navigation systems that are external to the plane. Most navaids (Navigation Aids) do require compatible airborne equipment to interpret or analyze information that they provide. Navigation Aids may be located on the ground; or in outer space. They may be interpreted by use of electronic signals, visually (with observers eyes, or by use of optical instruments), or photo-optical sensors. Most Aero Navigation systems usually involve ground based transmitters, or natural systems like stars, that aid pilots in determining their location on the earth. Some are as simple as rotating beacon lights atop towers. A few are so complex that exceptionally sophisticated integral computers are incorporated into the airborne equipment. Some are passive; requiring no transmission of signals from the aircraft. Others are active; requiring that some form of energy be transmitted from the plane. Most require special tools & "equipment", knowledge, & techniques.

Navigation Systems may directly or indirectly provide other info, such as time & distance to the next "waypoint" or destination, drift, ground speed, or wind information. Most require associated airborne equipment. It may provide a positive fix; or simply a LOP (line of position) which the plane is either crossing or following.

Without Aerial Navigation, & Gen-Av (General Aviation), most industries, communities, & cities would no longer thrive. The author watched as the truth of this statement unfolded over the years in 2 very small Midwestern towns located 12 miles apart. Each had a small normally unattended airport, which they occasionally allowed to deteriorate (runway condition, etc.). As 1 community "cared for" its airport, small industries moved in, & as they allowed them to fall into disrepair, industry actually moved out. They appeared to cycle alternately, so that as 1 community grew, the other "faded", & vice versa; repeatedly, over the years.

3.1.2 Aero Nav Users

The "Navigator" was a necessary part of the crew of most large planes before, during & for a few years after WWII; & on long flights in moderate sized planes, such as Amelia Earhart's "round the world" flight. The role of Aero Navigator changed as Aero Navigation systems evolved. See Appendix D.e for an expanded discussion of this.

The course includes some Aerial Navigation systems that are used only by large commercial operators (airlines & cargo) & military operators, but concentrates on the historical to the most advanced Navigation systems used by both the simplest & the most advanced small privately owned aircraft in the world; as portions of the most advanced Gen-Av fleet in the world; the U.S. Gen-Av includes private users whose main purpose in flying is for personal business, pleasure, or corporate use, such as executive travel, product deliveries, technical services, sales travel, & much more. Fed-X & UPS fly airline type planes solely for their cargo operations. Genav is much larger than the other segments of aviation, not only in the U.S., but also in most other advanced nations. Even in the most primitive countries, Genav is absolutely essential to many forms of commerce, medicine, & even religions. Gen-Av has more pilots & planes than the Airlines in the U.S., & even flies more miles & hours.

A significant portion of Gen-Av in recent years has been aircraft developed in conjunction with the EAA (Experimental Aircraft Assn). Many members of the EAA have actually developed concepts, designs, & materials that the major aircraft manufacturers & industry have copied, to the great improvement of their product; from lightplanes to large airliners & military aircraft. The annual AirVenture Oshkosh fly-in is sponsored by the EAA. That fly-in is internationally famous; actually attended by multiple 747s from Australia, for example. FAA flight controllers are the "best of the best", & all are volunteers. The "best" are necessary because the traffic is **actually ten times** as great as at the world's busiest airport; but only for the 9 day air show. During this air show it is not uncommon to see planes land or T.O. (take off) side by side while another pair of planes are half way down the runway doing exactly the same thing; 2 long; 2 short, SBS; **only at AirVenture Oshkosh.**

3.1.3 Aero Navigator-Pilot Requirements:

3.1.3.1 The flight physical for pilots is not as rigorous as one might expect. Only ailments that result in unexpected loss of facilities are routinely cause for rejection. Many pilots fly with only 1 eye. Heart problems do not always cause loss of flying privileges. High blood pressure rarely does. Some waivers are commonplace. Nor is age a factor. A retired 82 year old Aeronautical Engineering professor flew a P-38 Lightning replica in Sept '09 that he had just completed. He designed it & built it with only his wife as a helper, in 15 years. Steve Whitman, who Whitman field in Oshkosh, Wisconsin was named after, flew aerobatic routines over his field to celebrate his birthdays in his 90s. He often won air races on a "shoe string" against better funded expert pilots like Jimmy Doolittle in the early days of aviation.

3.1.3.2 A little known fact is that **English is the "official" language of commerce worldwide; & total fluency & comprehension is mandated for all aviation & marine communication**. Specifically, a pilot must be fluent in English; be able to speak, read, write, & **comprehend** English before he may fly in the U.S.; & in fact the entire world. Both written (now taken on computer) & flight pilot exams are conducted entirely in English. Inability to speak flawless English puts others, as well as the inept pilot, at great risk. Difficult to understand accents are a serious hazard. Having lived in a beautiful & fascinating foreign country (& traveled in most of Europe) for over a year, & "literally suffered through" a few months with less than total fluency in a "strange language", the author & his wife are "astounded" that some who enter the us illegally are too lazy &/or inept to learn English. They obviously broke the law to move to, & stay in the U.S. Legal immigration, of course, requires fluency, including "comprehension", in both written & spoken English.

3.1.3.3 The licensing requirements are discussed in detail in Appendix C. Note that the ATP license requirements are discussed in paragraph C.e.e.e. U.S. Airlines ATPs of the future took a major step backward in late 2009 when a few unlearned politicians irresponsibly elected to destroy the system that has worked so very well for many decades. Except for military pilots, for decades, the norm was for young flying enthusiasts to start, as most pilots do, by going to the local airport to hire a CFI & plane, & learn to fly.

Would-be airline pilots had no choice except to spend more than they would actually earn for the next 5 to 10 years obtaining a commercial license & instrument rating.

That was within reason for a fortunate few because they could fly as co-pilot for an airline with as little as 200 hours. This arbitrary, reckless, irrational bureaucratic mandate precludes flying at the controls of any airliner until building 1,500 hours flying time, & sufficient expertise & experience to obtain an ATP. One irresponsible decision precludes that. In fact, many current airline pilots will be terminated. To build 1,500 hours, including some heavy jet experience, would require a pilot or an airline to pay in advance half what the pilot would earn during his entire career. It will most certainly result in a major crisis for airlines.

3.1.3.4 A few of the rules of the air are discussed in detail in Appendix G.

3.1.4 A popular misconception of the uninformed regards the safety of Gen-Av planes. A safety conscious, properly trained pilot who maintains currency is generally considered several times as safe as a similar, cautious driver. The pilot's safety is essentially totally under his own control. The author has had hundreds of times as many brushes with death in driving than in flying.

The most frequently voiced concern about aircraft safety is that they "fall out of the sky" if the engine fails. They, in fact, glide many miles under complete control in the extremely unlikely event of an engine failure. Extensive, detailed, interesting additional information on flying safety, including glide range is expounded upon regarding, in particular, lightplanes, in Appendix B.

3.2. Engineering vs. Aero Navigation

3.2.1 Most Aero Navigation systems, & their predecessors, were developed by Engineers or scientists, as were the instruments, tools, sophisticated airborne avionics, nav aids, & devices that now facilitate the myriad of Aero Navigation systems. Progress over the decades generally resulted in improved accuracy. Some reduced Aero Navigation work load. Some were simpler; others more complex.

Aero Navigation draws on several fields of Engineering, including electronics, optics, mechanical, math & trigonometry.

3.2.2. Serious involvement in the field of Engineering is enjoyable, challenging, & rewarding; as is Navigating & flying a plane. Aero Navigation is one of the more technical aspects of flying, & the background theory of some Aero Navigation systems is highly technical. Both theory & application of Aero Navigation are fascinating to most Engineers.

The reader is undoubtedly intimately familiar with complex vectors, as used in Engineering. The wind vector, though only 2 dimensional & simpler, is very useful to a pilot, & quite easy for an Engineer to comprehend. Understanding the wind vector is absolutely essential to Aero Navigation. Cartesian Vectors are not the norm. Solving wind vectors forward & in reverse can be difficult using manual methods (ACAD or manual drafting). An "ancient" so called "computer" is still considered essential, & is both simple & effective; the E-6B. A person can fly without detailed knowledge of Aerodynamic theory, or extensive knowledge of the engine, but a functional knowledge of Aero Navigation is essential. Most pilots today are accomplished navigators, but some are only proficient in 2 to 4 Aero Navigation systems. This could, & has occasionally led to off field landings.

3.2.3. Many Engineers, including the author, do not recall a time when they were not fascinated by airplanes; much like the technical things that led many into the study of Engineering. The thought of Navigation was not an issue until they realized how easy it is to become disoriented after a few turns; indeed that Aero Navigation was a necessary part of flying. The author's aviation activity began as a very young boy, building small scale model planes; then building & flying control line, & eventually RC models. He requested acrobatics during his 1st airplane ride at age 12, but still has no idea just what maneuvers the instructor performed in the J3 Cub (see Note 1 below) on that flight, even though he later received aerobatic training. At 16 he took his 1st lesson, & obtained the 1st of many (most available) licenses & ratings at 17. He contemplated joining the USAF, or flying for a small airline that actually hired low time pilots with only a high school diploma, but chose to study Engineering instead. He has flown & navigated mostly lightplanes all over the U.S. numerous times, into Canada, deep into Mexico, & to the Bahamas. He has personally flown (sole manipulator of controls; soloed most) 45 types including the famed Pitts aerobatic biplane, a small jet (for several hours), turbo prop (King Air), sailplanes, amphibians, experienced one "dual" hot air balloon ride, & even the Goodyear blimp for a few minutes. He has used nearly all of the Aero Navigation systems described in this Aerial Navigation PDH series.

3.2.4. The modern phenomenal GPS might seem to eliminate the need for any other Aero Navigation system, but that is far from true. The GPS did not automatically obsolete all other Aero Navigation systems. An IFR certified, panel mounted

GPS costs several times as much as a Navcom (OMNI based Navigation unit in same case as a Communication device), for example. Flying without OMNI is inconvenient at best, even if a GPS or LORAN is aboard.

Another potential hazard & problem for GPS & LORAN users is that the government will certainly change “codes” &/or delays to render them both useless to all except the military if the U.S. is threatened with an enemy attack. Disabling them for non military use might result in very dangerous loss of function; or worse, provide erroneous info that might result in innocent pilots & passengers flying into a mountain; or fuel exhaustion. Certainly the ability to disrupt GPS output offers great advantage to national defense by confusing a technologically advanced “enemy”, who may rely on the most advanced Aero Navigation systems. This possibility justifies retention of competence in Map Reading as well as OMNI even if the Aero Navigator & pilot have a GPS. In the event of a major terrorist attack on the infrastructure, it is possible that even the electrical grid will be useless. Map reading may be the only practical Aero Nav system available.

A serious concern with the GPS is that satellites are deteriorating with age, with some loss of accuracy & reliability. This is a very serious safety issue for many. Replacement satellites are far behind schedule, so there is a possibility that GPS could suffer a major loss of accuracy.

An irresponsible decision by the administration overruled all experts & users to initiate closure of all LORAN transmitters.

Another reason that GPS & LORAN have not taken over such that all other Aero Navigation systems could be decommissioned is that even the best navigation equipment is subject to failure. Airborne instrument, satellite, & ground based or airborne navigation transceiver (a transmitter with integral receiver; generally simplex) can malfunction, so redundancy is important. That includes ability to resort to an unrelated Aero Navigation system. Planes have actually crashed because the pilot became so complacent that he could not navigate without his primary Aero Navigation system; when it failed. Even the most primitive & out of date navigation system is useful when the favored navigation system fails. After an emergency landing in a wilderness, a navigator could use knowledge gained in this course to orient himself & proceed to a safer location. Unfortunately, many pilots & navigators do not know a few of the lifesaving “tricks” that are included in this Aero Nav course.

3.4.5. Some of the information covered in this Aero Navigation course could literally save a person’s life; in some cases even if he is not a pilot.

3.5. Aerial Navigation Practitioners; Navigators & Pilots who Navigate Airplanes.

3.5.1. The “Navigator” was a necessary part of the crew of most large planes before, during & for a few years after WWII; & on long flights in moderate sized planes, such as Amelia Earhardt’s “round the world” flight. Most small planes, including fighter aircraft, obviously did not have the luxury of a full time navigator. Navigators have largely been displaced by modern avionics that allow the pilot to more readily perform all necessary Aero Navigation functions. The FAA still has a flight certificate (license) for Navigator, & the USAF issues a multiple rating that includes that of Navigator.

3.5.2 Modern Aero Navigation systems have virtually eliminated the need for a dedicated Navigator, even on long trans-ocean flights by large aircraft. Aero Navigation is an important part of all levels of FAA pilot licenses.

The most basic unlimited pilot license is that of Private. Commercial & ATP (Airline Transport Pilot) follow. The Instrument rating may be added to each of these 3 certificates. The ATP does not actually have an Instrument rating, but it still includes the “authority” to fly instruments. The number of instrument rated pilots has been increasing over the years, as the IFR system was improved & simplified. Many, if not most, instrument rated pilots do not actually enjoy instrument flying, since it is rigorous & demanding. Some Instrument rated pilots admit that they fly IFR only to climb or descend through a cloud deck, preferring VFR on top, even if filed for IFR. The author is one who thoroughly enjoys every type of flying he’s tried, including IFR. He routinely flies 5 or 6 consecutive hours, or occasionally twice that, after a refueling stop, while “in-the-soup” (engulfed in clouds) from take-off until near the ground on landing approach. He has always “filed” IFR (see note 1 below) for “mid cloud height”, when practical, to increase the probability of remaining “in-the- soup” for the entire flight, to maintain proficiency, gain experience, & simply to enjoy “solid soup” IFR flying. It is certainly more pleasant & rewarding than to fly with an awkward IFR practice hood. A better option than the hood is to modify a pair of plastic safety glasses to obscure the view outside of the cockpit. IFR is easier & more pleasant in a good stable “platform” such as the authors Cessna single engine lightplane. Some of the 45 ”types” that he’s flown certainly would not have been pleasant to fly IFR, even though all were a joy to fly VFR. Some were quite a challenge to fly under some circumstances, or to land, even though landing is one of his greatest pleasures in flying.

Note 1: An IFR flight plan should always be “filed” before entering IFR conditions. If essential to wait until airborne to file

IFR, he must either obtain pre-approval or remain under VFR conditions until cleared to proceed.

3.5.3. Who Flies Planes, & Why?

Every “type” background, avocation, education, & occupation is represented by pilots.

Some sign up for flying in the military because they have a great patriotism, or they prefer it to the trenches, or just for the excitement, but probably most to fulfill their lifelong dream of flying. Some because their pilot-father or a friend expects it; or wants company.

Many wanted to fly since, literally, infancy. The author’s first born son actually said the word “airplane” at only about 6 months; possibly even his first word. He flew as a passenger from a toddler until he left home. He flew gliders before age 14, & finally the family Cessna.

Alan Bean, one of the earliest Astronauts, is now an artist. He has absolutely no interest in space, & apparently none in flying. Buzz Aldrin is still tremendously interested in space flight. Hoot Gipson is a very enthusiastic pilot, even continues to race very high powered planes & to set various records.

Many retired pilots continue to fly solely for the money, since they are qualified to. They are the ones who quit flying the minute they leave the position that demands those skills, & never look back.

Many astronauts, private pilots, airline pilots, & military pilots love flying; it’s “in their blood” as the saying goes; a very important part of their life. One of the several dozen Astronauts the author has either known, or at least met, over the years was as a mission approached, not allowed (by NASA) to fly aerobatics at the local airport that they both flew out of. A story told of him was that as his launch date approached he went to the airport with a “long face”, & explained why, when asked. The next time he went to the airport someone handed him a false moustache & nose, & said, here XYZ, you’re no longer XYZ. So he went out & flew aerobatics with the “disguise”, thus the XYZ.

An ATP (& Captain) was asked after flying for a decade if it was "like driving a bus". She replied that it was, in fact, very exciting.

The crew & passengers of the Airbus A320, U.S. Airways flight 1549, Jan 15, 2009 should be very thankful for the fact that Capt Chelsey (Sully) Sullenberger was in every way a “pilot’s pilot”. Flying was not just another job to Sully. It seems evident that he flew for the “love of flying”, & took every aspect of flying, & his own proficiency, very seriously. He was an aviation safety expert, a Sailplane pilot, a former fighter pilot, with 28 years as an Airline pilot. His co-pilot was new to the Airbus, but fully qualified to fly it, & a highly experienced pilot. The 5 minutes that they were airborne after total power failure at 3,200’ altitude did not give him enough time to read the 3 page checklist to Sully; nor could Sully have complied with all items, as busy as he was flying the plane, making some very perceptive observations, & some very wise decisions. That 5 minutes was in fact gliding, just as Sully had done in sailplanes, except at 3 or 4 times the speed & several times the sink rate. There was no possibility of a second chance if he’d made a wrong decision. Sully’s superb skill, experience, knowledge & mental preparedness did save the lives of 150 passengers & 5 crew members. A little less skill the ending would have been catastrophic. A very big factor was his expertise at “flying by the seat of his pants”; a natural pilot. He was part of the plane when he flew it. WWII fighter pilots often say that if a pilot were not a part of the plane, & visa versa, they would not be successful fighter pilots. Sully had much less time than he should have had, & absolutely no room for error. The slightest difference from his actions would probably have resulted in a disaster. Some do say “God was really in control”. Had even 1 of the many small boats, including ferries, been in his path, there would been a mass of tangled metal. But had the myriad of ferries been just a little further away, the passengers could not have survived a long wait while standing in ice water on a slippery wing. The Airbus actually included some provisions for ditching, but weight considerations precluded the strength of a “seaplane hull”; sufficient to withstand a ditching free of damage. Even a nearly imperceptible light chop literally “hurts” on a seaplane landing at 60 mph; much less 150. The seaplane hull slants up at the rear, & is very narrow at the aft end, to reduce the very hard “Slam-down” upon tail end contact, which would result in a rapid nose-down pitch.

3.6 Aero Navigation Basics

The most basic “tools” used for Aero Navigation are specialized aviation versions of maps, which are called charts, E-6B (also called DR computer), Weems plotter, compass, airspeed indicator, altimeter, clock, & thermometer. The reader may ask why a thermometer; read on. Most more advanced “tools” are now called avionics, & are usually required for specific Aero Navigation systems.

3.6.1 The Mercator Chart; the Lambert Chart; other Charts, & the magnetic field of the Earth, & other effects upon the use of charts & the direction of flight are critical to Aero Navigation:

To understand any navigation system the reader should 1st recall the mapping systems that he most likely learned in elementary school. A refresher is included in this introductory course. The "grid system" that is discussed in this Aero Navigation course was developed because the 2 projections shown below are impractical in the polar regions. Navigation also requires some knowledge of the earth & its magnetic variation & fields, as well as the various charts used.

Spherical geometry is significantly different than the more common Euclidean geometry. It is obviously impossible to accurately depict the earth as a flat plane. Some of the many different "projections" make a credible attempt to eliminate land mass distortion. Charts do "distort" the land mass features. The Lambert chart more closely matches the true earth features in the immediate vicinity of the area of greatest interest.

3.6.2. The Mercator Chart:

The Mercator chart depicts the features of the earth as it would appear if features were projected onto a cylinder that was wrapped around it at the equator with the centerline of cylinder & earth true N-S pole coaxial. Thus the cylinder is tangent to the earth only at the equator. Fig 1 illustrates that parallels are plotted with increasing separation on the chart as Latitude increases. The Mercator lat – long lines form a square at the equator vs. 2:1 ratio rectangle at 60° latitude. The Mercator chart illustrates meridians as parallel; & thus perpendicular to the parallels. The actual meridians on the earth, of course, are parallel only at the equator, & converge at the true North & South poles. This major deviation from the globe results in significant distortion of the land mass features; particularly at large latitudes.

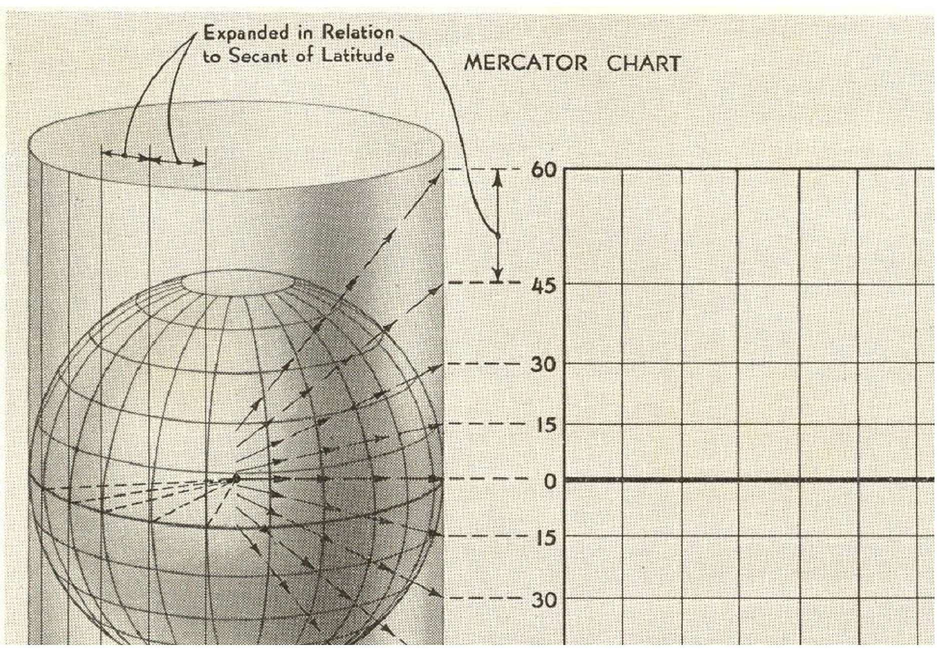

Fig 1 - Mercator Projection

A factor that is important to Navigators is that a straight line drawn on the Mercator chart, called a Rhumb line, traces a line on the earth that is severely curved, so is actually much longer than a "great circle". The Rhumb line crosses all meridians at the same angle on the Mercator projection. Unfortunately the easiest way to navigate is to hold a constant heading, which leads the aircraft on a line that actually curves severely, & is much longer than a true great circle route; see Fig 2. On short flights the excess flight distance is minor, but on long flights it becomes excessive.

A great circle is achieved by drawing a circle around the earth that has an axis that passes through the center of the earth. It traces the shortest distance along the surface of the earth between any 2 points on the surface of the earth. A great circle can be drawn between any 2 points on the face of the earth. A great circle is essentially an angularly displaced Meridian. A great circle crosses each successive meridian at a different angle. Thus to follow a great circle, the Aero Navigator must continually change TH (true heading). With most Aero Navigation systems, it is difficult to determine the

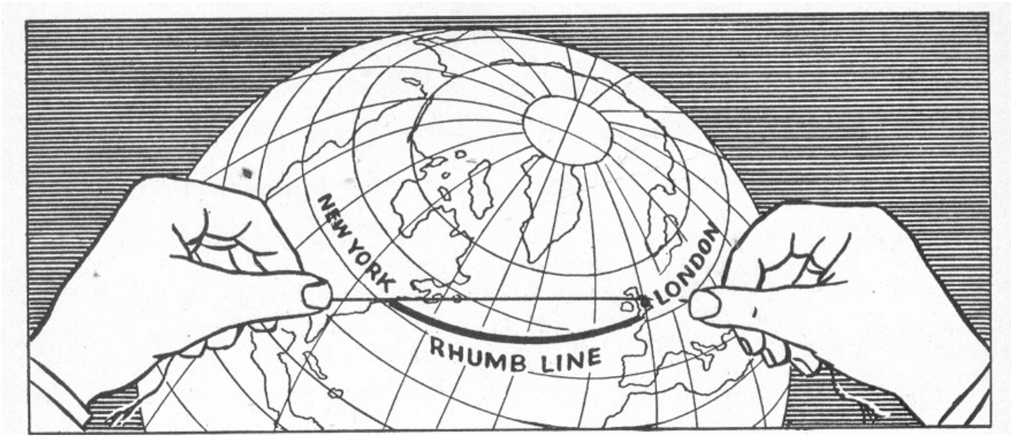

Fig 2 - Rhumb Line

correct instantaneous TH. A great circle axis is the longest line that can be drawn through the earth, & can run from any point on the earth to the exact opposite side. The above disregards the fact that the earth is not "quite" a true sphere. In fact, it varies only slightly from a perfect sphere.

The circumference of the earth at the equator, which obviously has an axis perpendicular with the rotational axis of the earth, is 360°x 60' / degree = 21,600 nautical miles (24,872.7 statute miles) at the equator.

The great circles that are called meridians have a slightly smaller circumference because the earth is not a perfect sphere. They have an axis that is coincident with the earth axis of rotation, but a circumference of 21,559.6 nautical miles (24,826.2 statute miles). Although the Mercator is the preferred chart for marine use, the distortion of the features of the earth & the "parallel meridians" precludes practical use for Aerial Navigation.

3.6.3. The Lambert Chart:

3.6.3.1 The Lambert Projection & its Limits

The "Lambert conic projection" chart depicts the features of the earth as it would appear if it were projected onto a cone that intersects the earth along 2 parallels of latitude. Thus the cone falls inside of the earth between the 2 parallels, & outside of the earth beyond the parallels, but never very far from the earth. The fact that the cone intersects the earth on 2 parallels improves the consistency of scale & accuracy of land features near the intersections. The further to either side of the intersections, the greater the distortion. The Lambert chart thus distorts land features much less than the Mercator projection. The Lambert chart projection method for the Northern hemisphere is illustrated in Fig 3. This intersecting cone results in meridians that are nearly parallel for the distance required for a typical aerial chart, which is known as a "Sectional". The features of the earth are depicted with acceptable accuracy near the parallels selected. Thus the aerial Navigation charts use cones with optimum included angle, & both "intersection latitudes" near the area of interest to optimize each & minimize land mass distortion. For example, the Houston Sectional uses the intersecting parallels of 25°20' & 30°40'. Likewise its area of coverage is between the latitudes of 28° & 32°13'. The Kansas City Sectional, being further North, uses intersecting parallels that are higher; 33°20' & 38°40' to cover the latitudes between 36° & 40°16'. The parallels do not match perfectly since a single projection covers several Sectionals. Ideally, since the KC Sectional is based on intersecting parallels of 33° 20' & 38° 40', the area of coverage should be more like 30° to 42°. The actual coverage of 36° to 40° 16' is used because that projection covers several charts. Modern computer capabilities could permit more closely matched Sectional intersection latitudes.

A straight line drawn on the Lambert chart is also called a Rhumb line. It is also longer than a Great Circle, if transferred to the earth, but not as long as a Rhumb line on a Mercator chart. The Lambert more accurately depicts the globe that it is intended to resemble than a Mercator. As with the Mercator, the Rhumb line on a Lambert chart crosses all meridians at the same angle. See Fig 2 for a comparison on a globe. The only great circle that actually crosses the meridians at the same angle is the equator; with a 90° crossing angles. Any great circle cuts the earth in half.

The shortest distance between the 2 points on the surface of the earth is a Geodesic; a segment of a great circle. A true straight line between 2 points is, of course, a chord, not on the surface of the earth; nor is it a segment of a great circle. It

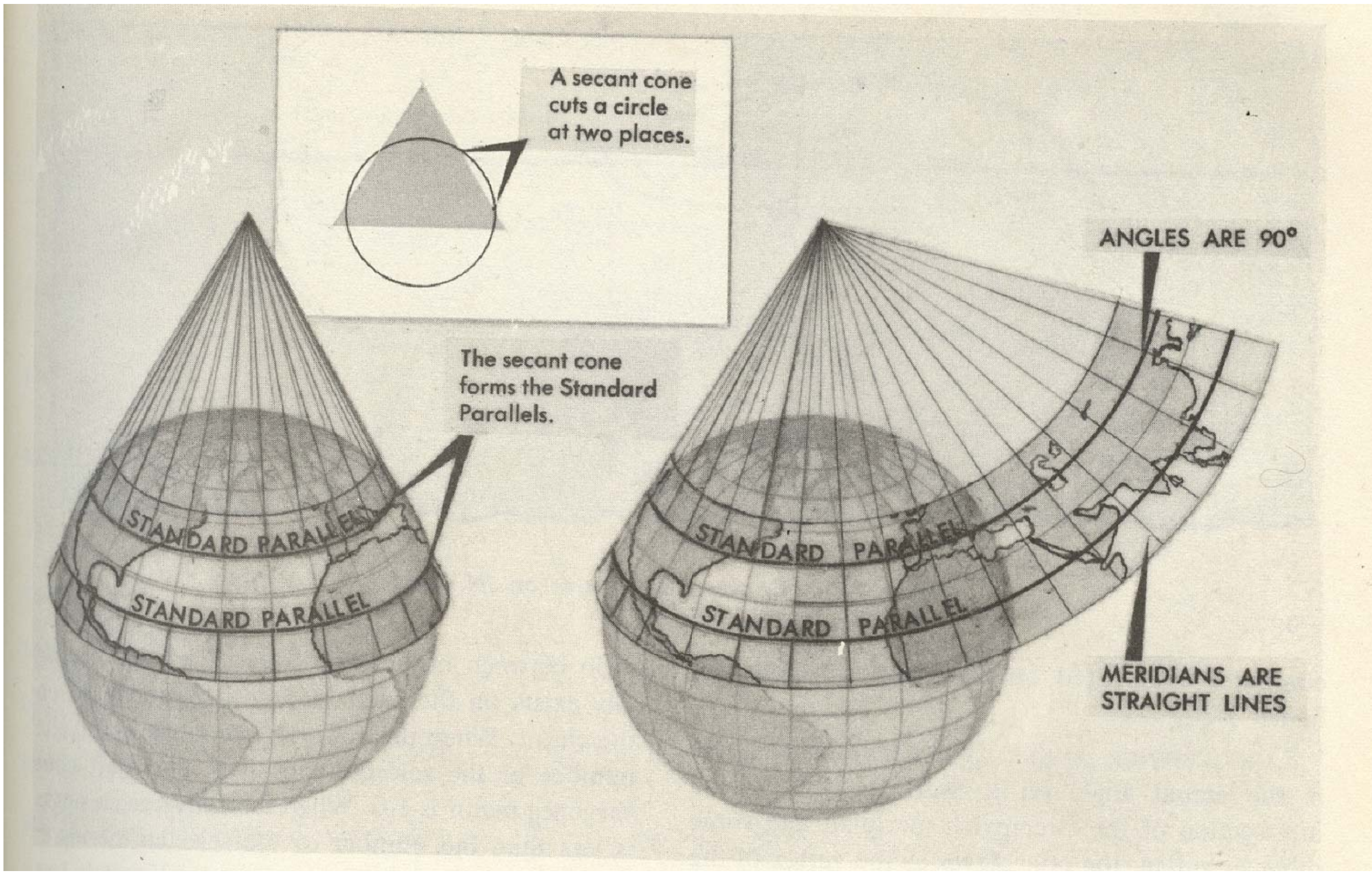

Fig 3 - Lambert Projection

passes through a portion of the earth. The equator is the only great circle that is also a parallel. The axis of a great circle passes through the center of the earth.

The great circle route, plotted on a typical chart, will curve to the North in the Northern hemisphere, & appear to be longer than a Rhumb line. The further North, the closer to an East-West orientation, or the longer the flight distance, the greater the disparity between the Rhumb line & a great circle. Fig 4 is a plot of 3 Great Circles drawn on a large Lambert map at progressively higher latitudes for East-West routes between the East & West coasts of the U.S. As above, true Rhumb lines would appear as a straight line between the end points on this map

Thus the Rhumb Lines corresponding to the 3 Great Circle "curves" are actually severely curved on the surface of the earth; & progressively more severely curved as latitude increases. "Ezmap" is a large internet web page that describes & assists generation of any projection.

A Rhumb line for a flight between NY & London is 140 miles longer than a Great circle route

The Aero Navigator has no "convenient" way to establish a Great Circle route other than to use a Navigation system that automatically selects it for him; some do. The GPS & LORAN always provide a great circle route. The modern internet offers some possibilities, as do some FAA provisions. Latitude-longitude Great Circle computations are discussed in the appropriate Navigation Aero Nav system. Lest the Aero Navigator choose to carelessly measure TC from meridians, he should consider the impact of the meridian "closing angle".

One such meridian is near the left of the enlarged Hobby Airport area Sectional in Fig 5. This line is the 95° 30' longitude great circle. At the equator 3° of longitude would be 180 nautical miles, but the further from the Equator one is, the fewer miles per degree of longitude. At 97N latitude, 3° of longitude is 158 NM (nautical miles) rather than the nominal (equator) 180 NM. The Sectional mileage scale also shows it to be 158 NM. Moving North to 36° N latitude we find that 3° of longitude would be less than 147 NM. This confirms the fact that the meridians taper slightly toward one another near the top of a Sectional chart. They obviously converge at the North pole.

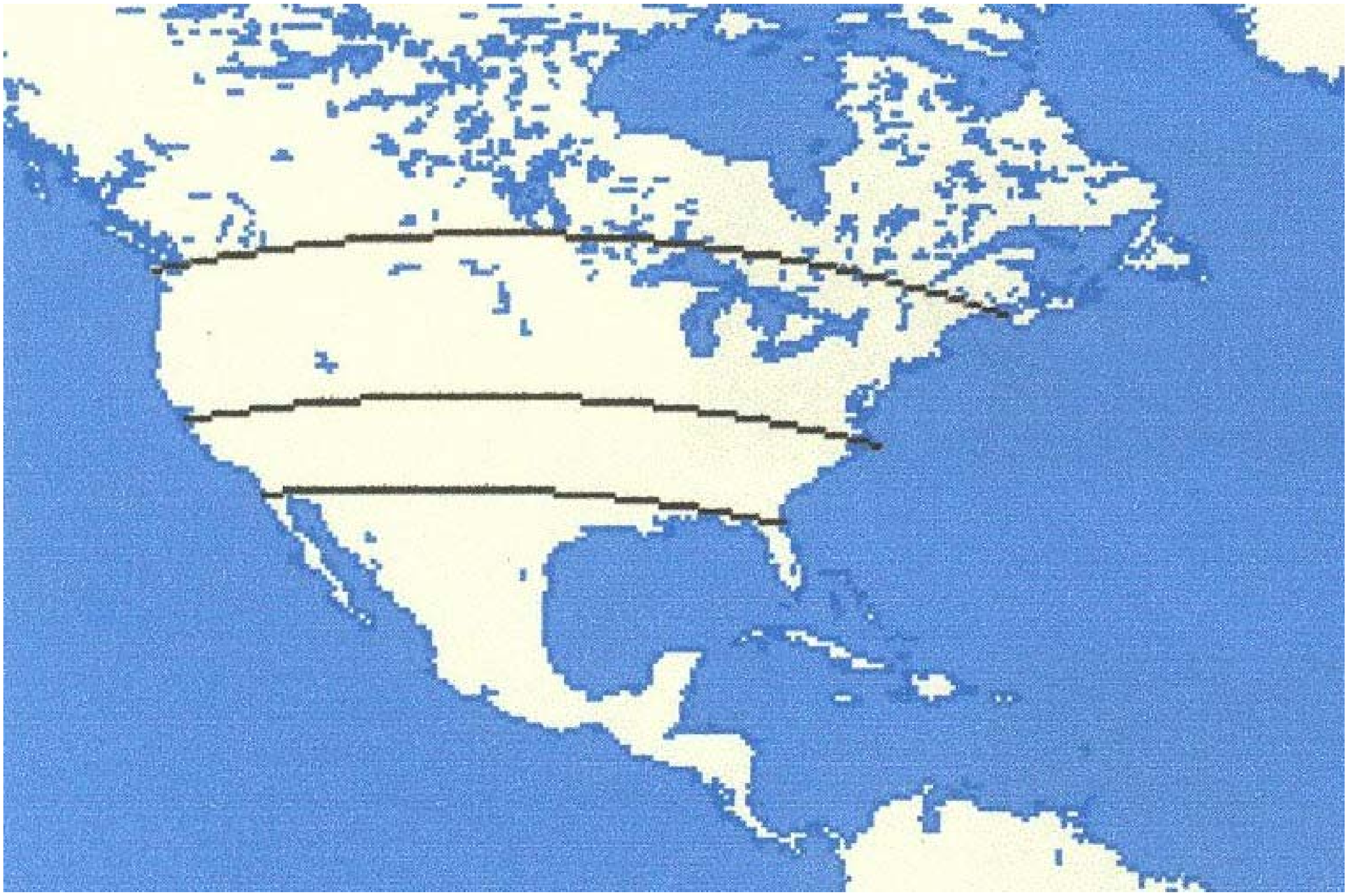

Fig 4: Great Circle Curvature on Lambert Projection

3.6.3.2 The Sectional (Lambert Projection) parallel sags about 3/16" at the midpoint on the Sectional. At the bottom of the same chart the same 2 meridians measure 35-3/8 apart, & the 36° parallel sags 1/4". These measurements translate to, on the statute mileage scale on the chart, 266.5 miles E-W at the 40° parallel, & 280 miles at the 36° parallel. These parallels (lines) sag 1.5 miles at 40° latitude & 2 miles at 36° latitude.

Another comparison is provided by physically measuring Meridian spacing on the Kansas City, Mo. Sectional. Near the top of the Sectional is the 40° parallel. Between the 90 & 95° longitude lines (great circles) the distance along the 40° latitude line is just over 33-5/8", while the 40° meridian spacing prove that a course error would result. For such flights a great circle route should be followed, if possible. The distance between the 36 & 40 parallels will be as with any great circle; 60 NM per degree, so 4° X 60 NM/degree = 240 NM. Measuring the Sectional confirms that; 240 NM.

Even though the meridians taper slightly toward the true North pole, they are sufficiently accurate for Aero Navigation purposes. Likewise, the features of the earth are reasonably accurate, & very detailed, on Sectional charts, except as stated above, the curvature of the Rhumb line. The process of map reading is discussed in detail under the map reading Aero Nav system in this series. Some "map reading" is nearly essential for any type of Aerial Navigation.

The Sectional is the most common VFR (visual flight rules; for fair weather flight) aviation chart, & is mandatory for both VFR & IFR flights within the U.S. It is the only chart containing detailed land mass features that is practical, & used for Aero Navigation.

Sectionals are printed on both sides, for the top & bottom portions of the coverage area.

The Haversin Equation could be used to obtain the distances between 2 points on a sphere, but there are disadvantages & complexities with that. Before hand held digital calculators, the haversin/inverse-haversin, with logs, & exponential treatment of trig functions, the problem in flight was overwhelming. Even now that would be a laborious task that is unduly

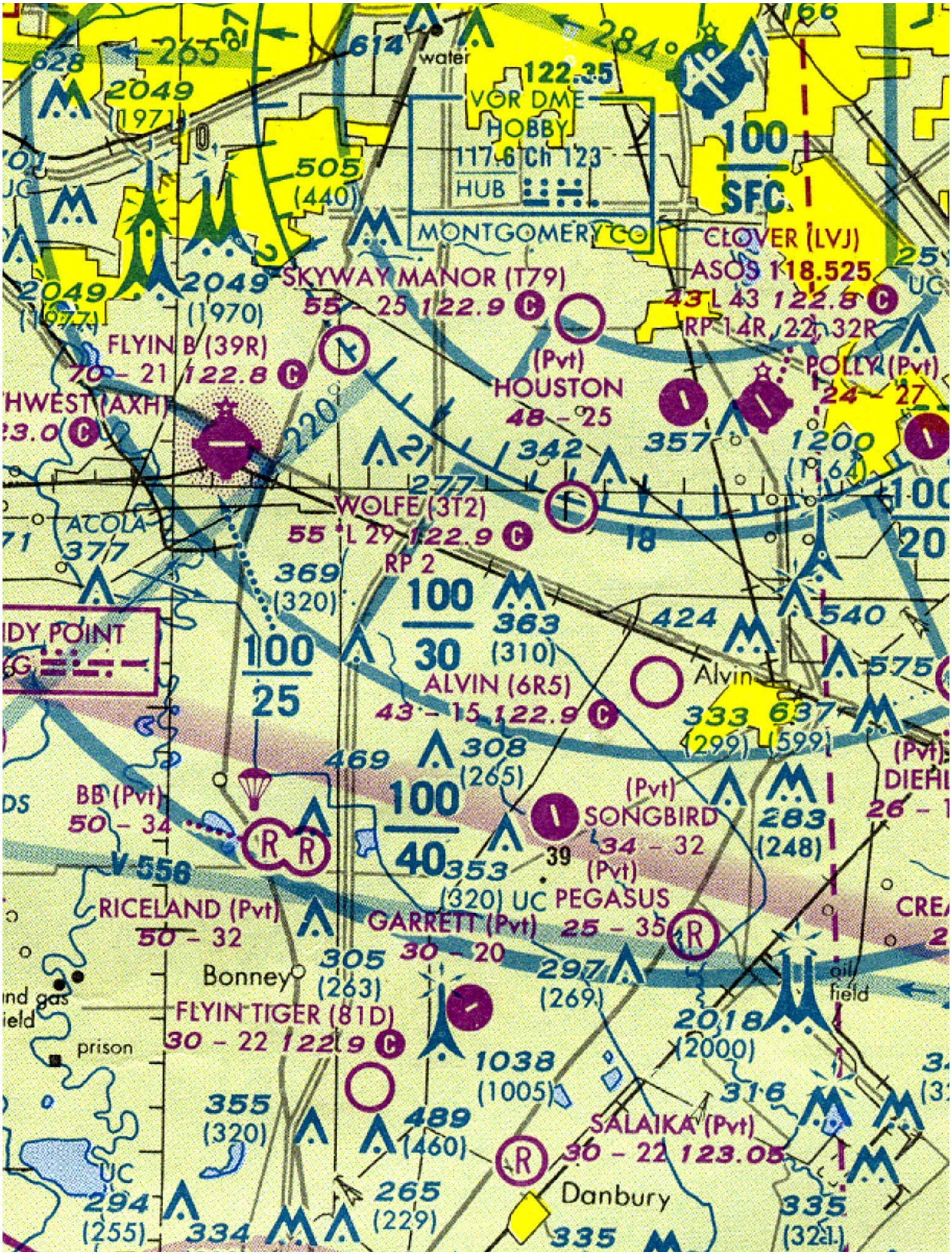

Fig 5 - Enlarged Houston Sectional

subject to errors. The air almanac & HO214 or later sight reduction tables not only simplify the process, but also reduce the likelihood of errors.

3.6.3.3 Establishing the Great Circle by use of the Haversin Equation

h = haversin (d/R), but must not exceed unity. $d = 2R \arcsin(\sqrt{h})$.

The spherical trig equations for the intercept method are (slow, complicated, & subject to errors):

sin (Alt) = [sin (lat)] x [sin (dec)] + [Cos (lat)] x [cos (dec)] x [cos (LHA)]

cos (Az) = { sin (dec) - sin (lat)] x [sin (Alt)] } **/** [cos (lat)] x [cos (Alt)]

Where Alt = altitude, lat = latitude, dec = star declination, LHA = local hour angle, Az = North azimuth of the star.

The haversin equation provides the distance between 2 points on the earth by following a Great Circle.

$d = 2R \arcsin(\sqrt{h})$

Where h = haversin (d/R), but must not exceed unity, d = distance between 2 points, R = radius of the earth (a compromise since the earth is not precisely round). The more complex haversin equations apply coordinates of the 2 positions on the earth. Comparison of chart distances with haversin distance will indicate the extent of extra distance that will be flown if following a Sectional vs. a great circle. More on haversin equations below.

3.6.4. Other Charts:

There are a few other specialized charts that are discussed in the appropriate places.

3.6.5. The Magnetic Fields of the Earth, & Magnetic Deposits

There are external Influences that must be considered in Navigating to a destination; earth magnetic field, aircraft EMI (electromagnetic interference) & wind effects that cause a plane to deviate from the intended course.
In case the reader is not familiar with the magnetic field of the earth, a simple illustration is provided in Fig 6.

This illustrates the general magnetic field lines & the impact of downward pull of these lines near the poles that are responsible for the compass dip (compass needle) that reduces the reliability of a compass near the magnetic poles.

Scientists do not fully understand the details of the magnetic core of the earth, but some think that it is due to the "dynamo effect" within the nickel-iron core of the earth. The mobility of the molten core seems to be partially responsible. The movement within the fluid core probably permits the noted shift in the location of the magnetic poles relative to the true poles of the earth (rotational axis). It does not appear that the predictions by a few scholars that the magnetic poles will soon "switch ends" (N to S; & visa versa) are realistic. It is known that the recent magnetic North Pole shift toward Siberia is 25 miles per year.

The magnetic North Pole was located at 73° N. latitude & 100° W longitude in 1968.
81.3 N. lat. in 2001.
82.7 N. lat in 2005.
At 1 nautical mile per arc-minute, & thus 60 miles per degree on any great circle, that means that the magnetic N. Pole was (90-82.7) X 60 = 438 nautical miles South of the true N. pole in 2005.

The magnetic variation Isogonic lines shown in Fig 7 are obsolete as discussed above re the magnetic poles shifting over time. It does indicate, on a large scale, the general values of magnetic variation around the entire earth. The letters E & W indicate the direction of the variation. The large difference in spacing between the Isogonic lines is caused in part by proximity to magnetic poles of the earth, but also to some extent, by magnetic disturbances, such as large iron ore deposits.

3.6.6. Aero Navigation Tools

3.6.6.1. Chart:

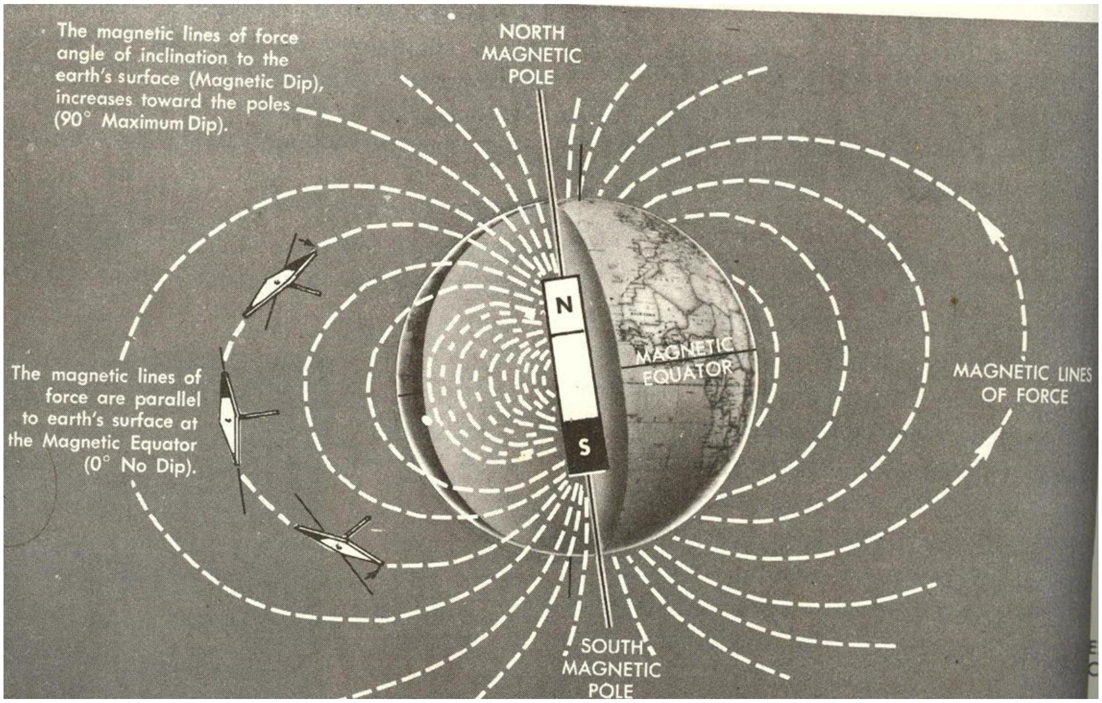

Fig 6 - Earth Magnetic Field; & Influence on Compass Polar Dip

The Sectional chart is the most basic VFR Aero Navigation chart.

3.6.6.2. The E-6B Navigation Computer:

Even though the E-6B was developed in the early days of aviation, it is still the favored essential D.R. tool. Without an E-6B or equivalent, D.R., & Aero Navigation in general would be impractical, if not impossible for use in lightplanes. The E-6B is an ingenious 2 sided hand held manually manipulated "computer" that allows Aero Navigators to perform an assortment of Aero Navigation computations. Both mathematical rotary slide rule & wind vector computation capability are possible.

3.6.6.3. The Weems plotter:

The Weems plotter is used during a “preflight” to determine the route distance & T.C. (true course; also known as ground track) between the departure point & destination.

3.6.6.4. Aircraft Instruments:

3.6.6.4.1 The Compass as an Instrument:

Some essential tools are in fact a part of the plane; for the most basic type of Aero Navigation.
Many consider the most important Aero Navigation instrument in the plane to be the magnetic compass.

The geomagnetic field would have the magnetic compass reading MH (magnetic heading). Another magnetic influence, however, prevents a correct reading of MH. Magnetic compasses are subject to magnetic influences within the aircraft (EMI; electromagnetic interference; also called RMI; radio magnetic influence). This EMI results in deviation from the correct reading, so is called deviation. Thus it overpowers the geomagnetic field enough to cause the compass to read CH (compass heading). Since correction of deviation is desirable, compasses are provided with tiny adjustable magnets implanted in the case to reduce the magnetic deviation errors. The Aero Navigator sees the front portion (face) of a simple “compass card” type magnetic compass cut-away; shown in Fig. 8.

Air turbulence & aircraft attitude changes preclude an exposed magnetic sensor. A sealed enclosure contains a damping fluid (kerosene).

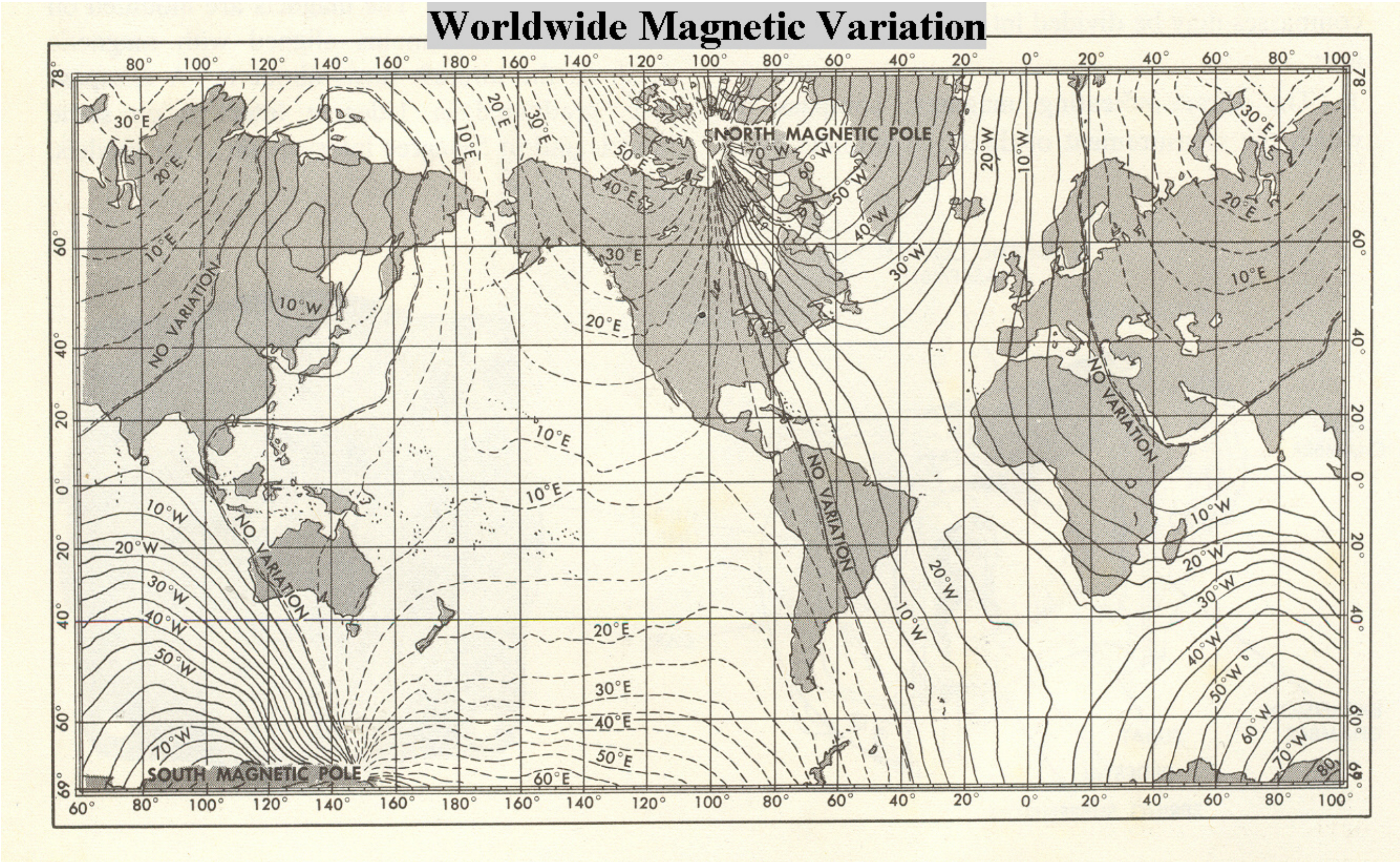

Fig 7 - Isogonic Lines Entire Earth

Because of the large changes in ambient pressure (at altitude), an elastomeric diaphragm is integrated into the compass to eliminate the need for venting. The precision low friction pivot is located well above the CG (center of gravity) of the compass card so that the card will remain vertical, barring outside forces acting on it.

The compass, as an instrument, does leave much to be desired. It is unstable, & has several undesirable characteristics. Its accuracy & resolution are limited. The compass card (conical frustum calibrated in degrees; usually with 5° minor divisions) suffers from several sources of error. When flying significantly above or below the equator there is a minor “dip” caused by the magnetic force of the earth exerting a slight downward force on the N (or S) pole of the instrument “card” (needle). This results from the magnetic North pole of the earth actually being slightly below the horizon. As the aircraft moves closer to the N (or S) pole this dip increases, further increasing the “dip” influence. The result is a total loss of reliability at latitudes above roughly 70°N or S. There is thus a large segment of the U.S., even, where the Magnetic compass is nearly unavailable This was illustrated in Fig 6 where the dip allows the vertical component of the N. pole magnetic force to pull the North (or South) side of the compass card down. Note the small compass needles shown on the left side; dip near poles vs. no dip near equator.

When far enough from the poles, the dip is tolerable. If a plane is flying straight & level, gravity keeps the axis vertical. In a properly coordinated turn (see Note 1), centrifugal force keeps the compass axis vertical with respect to the aircraft vertical axis rather than the earth vertical. Thus the compass is “tipped” relative to the earth; potentially seriously. This allows the horizontal component to steer the North pole of the compass to act as though weighted toward the low wing side of the plane, resulting in the compass indicating incorrectly. This is called the “Northerly turning error”, which is most severe on N & S headings. The illustration shows the compass card dipping as it approaches the poles. When turning while heading in the Northern semi circle (between West & East, but North of both) it briefly indicates a turn opposite to the actual turn. When turning from a Southerly heading it indicates correctly, but it exaggerates the turn.

. See Note 2 below for a related explanation on how this feature can indeed save lives in the event of a highly unlikely massive avionics failure.

There are also 3 similar but less severe turning errors that can occur. One is related to aircraft acceleration, another to

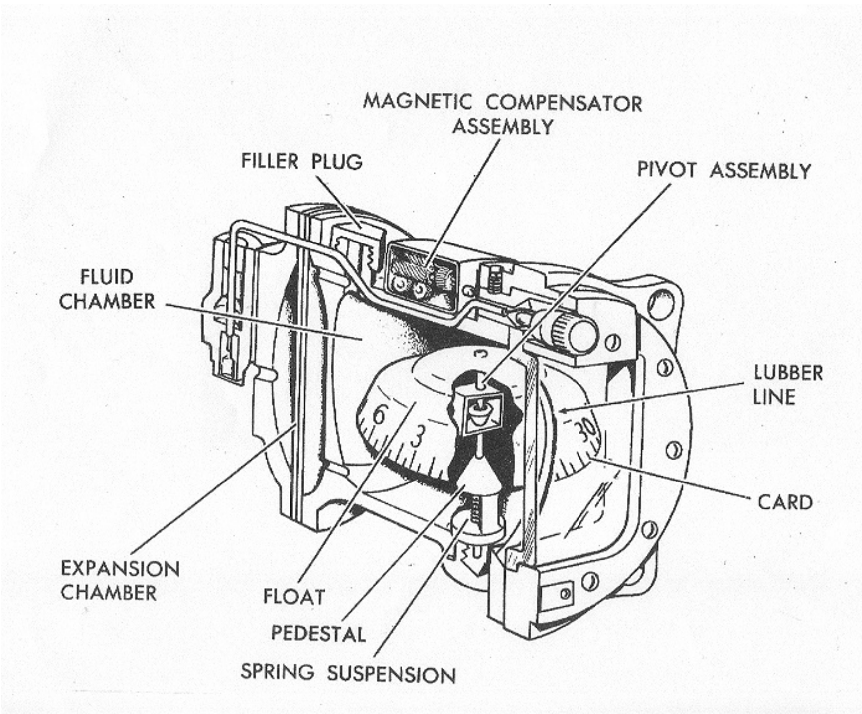

Fig 8: Magnetic Compass

"swirling" action (from excessive turning of the plane) or the liquid within the compass, & the last occurs if the plane is flown "out of trim" (with 1 wing low).

Note 1: T&B & Turn Coordinator

In a properly banked turn a carpenter's level placed across the instrument panel will show that the wings are level, rather than banked. The reason for this is that the plane is neither skidding nor slipping. Gravity pulls the fluid & compass card down, & centrifugal force pulls them to the side. The vector sum of these 2 forces will be perpendicular to the lateral axis of the plane. It also means that the slipstream is properly centered on the plane; not crossing wings, etc. at an angle, such as moving to the left as it progresses to the rear. The bubble floats to the "effective" high point. The "bank" portion of the T&B is in fact an inverted level, using an agate ball as a weight instead of a bubble as in the carpenter's level. The level portion of the T&B is used for reference, & serves the purpose of verifying straight flight & coordinated turns; neither skidding nor slipping; the plane is properly banked .

Note 2: Two Life Saving "Tricks":

A. When a plane is heading generally in a Southerly direction, it is actually possible to keep the wings level by holding any heading; & thus to fly with "no other instrument whatever" (other type of compass, DG or AG, etc) in a "dire emergency only" (such as when suddenly & unexpectedly surrounded by clouds that were not forecast, at night, in a plane that suddenly lost electrical power to operate & illuminate the instruments; or if caught unexpectedly in a plane that has no gyros whatever). This "tidbit" was articulated at an FAA safety meeting; but was apparently never published. It could certainly save lives; but should not be deliberately attempted under IFR conditions. When turning in the Northern half of the compass card, it is absolutely impossible to use this tactic to keep the wings level by use of the magnetic compass; or even to fly straight & level.

The lead & lag characteristic of the magnetic compass also makes it difficult to "roll out" of a turn precisely at any desired heading by reference to only the magnetic compass. Reading the magnetic compass during the turn is not very informative. Lacking a "full panel" the only gyro available is the T&B (or turn coordinator); or "primary panel". The primary panel also includes all of the standard basic instruments which are "mandated" by the FAA. These include items like the altimeter & air speed indicator. To overcome the inability of the magnetic compass to provide reliable heading info during a turn, the turns must be "timed" by use of the T&B instrument. This is accomplished by banking at a standard rate; a 2 minute turn. Allowance must be made for entry & exit time; nominally a 90° turn will take 30 seconds. The "full panel" consists of the “primary panel” plus an attitude gyro & a directional gyro. Some planes have no gyros whatever, so IFR conditions absolutely must be avoided.

B. In the very early days of aviation, pilots had no IFR capability whatever. Occasionally a foolhardy pilot chose to take off with insufficient ceiling; cloud bases too low. In such a case, he would fly toward the sun, if the cloud layer was relatively thin. If he could see a bright spot in the clouds caused by the sun, he would head directly toward it in a gentle climb, & keep the bright spot centered on his windscreen laterally until he exited the top of the cloud bank. Simultaneously he kept the bright at the vertical level where it was upon entry on the windscreen until he broke out above the clouds. Very foolish, but it might be a life saver if unexpectedly engulfed in a cloud. Conversely, a grave risk is that flight under a higher density cloud would eliminate the bright spot entirely. Since then flying into a cloud without proper clearance from the FAA & instrumentation was made illegal, although there are exceptions.

In reference to the above, the subtle problem with flying in clouds defies the logic of the inexperienced. Most adults can walk normally in the dark. They know which way is up. Even underwater it is possible to sense the vertical. But in a plane, gravity can be overpowered by centrifugal force. In a properly banked (coordinated) turn, the plane always feels level. Pump the wheel (or stick) back & forward a few times & very gently enter a turn & they may think they are climbing or diving, but not in a turn. The same can even be true in inverted flight if changes are subtle. Thus a pilot not trained in instrument flying will eventually (actually typically in 3 minutes) be totally disoriented upon entering a cloud.

Even with its problems, the compass is the most reliable & trustworthy instrument in the plane. Its error is never very large. The author is not alone in having become disoriented (or lost) after a joy ride looking over beaches, mountains, or other points of interest without regard for the compass reading or land features. Two highly experienced pilot friends laughed as they told of a flight with many heading changes while enjoying the scenery, & dodging rain showers. When it was time to return they disagreed on which way to head to return to the home base in the J3 Cub. As they debated the correct heading they eventually realized that they were both wrong about the direction they were flying. The compass solved that problem, but not their location. In dodging a few small thunderstorms, with numerous random angle turns, it is quite easy to become disoriented & lost while flying VFR. The author, after a similar experience, once decided that his OMNI was reading incorrectly when it seemed to call for flying around the “wrong side of a mountain”. Needless to say, the OMNI was correct.

Fig. D6 in Appendix D illustrates, in effect, several directional instruments. No two are functionally the same, but they have similar appearance. A DG resembles a slaved gyro compass, remote compass, ADF, vertical card compass, & even an OMNI CDI, or similar vertical discs. Some are infrequently found in lightplanes.

The vertical card compass is less susceptible to the various errors that are discussed below. As a result they follow the aircraft heading much more closely than the more common magnetic compass, with improved accuracy of achieving the desired heading during a turn. It is also more stable than the typical conical type compass, although both are powered solely by the earth magnetic field.

The remote compass, though not often found in light aircraft, is a superb vertical card compass. It is superior because it follows the aircraft heading even more closely than the excellent vertical card compass, so is greatly superior to the common “magnetic compass”. It avoids much of the deviation error by placing the magnetic sensing unit in the tail cone; well aft of the major electrical disturbances in the aircraft. It is less susceptible to turning errors than most magnetic compasses. The tail cone magnetic sensing unit is much larger than a panel mounted compass, to improve magnetic field "leverage" & thus sensitivity & accuracy. The panel mounted unit, with its compass rose, is only an indicator that receives information from the sensing unit/sender by use of shielded electrical wiring, to further reduce RFI (radio frequency interference) induced errors.

The DG is illustrated in Fig. D6. It is solely controlled by a gyro, with no link to magnetic North . It requires manual adjustment to match the heading shown on any magnetic compass. Gyros precess, so must be periodically corrected manually. Note that 3 of the above 4 instruments are shown on the instrument panel of the Cessna that the author owned for 41 years; the entire “Equipment List” is also given below the illustration. Each of the 33 Avionic items is described in Appendix I.

The Slaved Directional Gyro is more informative than the others, above. It is essentially a DG that is automatically corrected by a unit much like the remote compass.

The HSI (Horizontal situation indicator) is an even more complex & useful variation of the vertical card compass, or DG. The HSI is discussed in detail in a later Aero Nav system in this series, & shown in Fig. D7 in Appendix D. It is exceptionally complex, but a true labor saver & safety enhancer; especially for IFR.

3.6.6.4.2 Airspeed Indicator

The act of Aero Navigation demands knowledge of airspeed. No other Aero Navigation tool or instrument provides IAS or TAS instantly. Some Aero Nav systems do provide GS. See Appendix D for an illustration.

3.6.6.4.3 The Altimeter:

Without an altimeter the pilot cannot safely approach a mountain range, cruise legally on an airway, fly at pattern altitude or possibly (depending on his altitude judgment skills) even land at a predictable point on a runway, or legally fly over a city. But to correctly Navigate, the precise altitude is also essential for (TAS) true airspeed computations. Detailed information on the altimeter is provided in Appendix D.

Altimeters must be adjusted to the current “altimeter setting” to read properly. The barometric scale is used to set the current reference altitude (SL) plane into the altimeter. Setting the barometric pressure into the Kohlsman window increases or decreases the indicated altitude. Each 0.01” Hg change on the barometric scale is equal to 10 feet of altitude.

The altimeter should be checked for accuracy before every flight. To check and set the altimeter:
a. Set the current altimeter setting on the barometric scale.
b. Check the altimeter reading at a known elevation and note the error in feet.
c. Reset the altimeter to the known elevation and apply either the difference in indicated altitude or in barometric pressure to all subsequent altimeter settings.

If the altimeter is set at 29.92 (assuming standard pressure; current altimeter setting), & the field elevation is 470 feet, while the altimeter indicates 400 feet, the error is 70 feet. The Aero Navigator can reset the altimeter to indicate 470 feet, the indicated altimeter setting (barometric scale) increases to 29.99, for a difference of plus 0.07. This difference must be applied to all subsequent changes in altimeter settings. The maximum allowable altimeter error is 75 feet. Altimeters exceeding this error should be checked for proper operation before flight. Altimeters are officially checked during the biannual transponder check.

3.6.6.4.3.1 Types of Altitude

● Indicated altitude is simply the value of altitude that is displayed on the pressure altimeter.
● Calibrated altitude is indicated altitude corrected for instrument - installation - position error.
● Pressure altitude is the height above the standard datum plane (29.92" Hg and +59°F).
● Density altitude is pressure altitude corrected for temperature variation. The pressure lapse rate above the ground varies with temperature. Since air expands with increase in temperature, warm air is less dense than cold air. This results in a lower lapse rate in a column of warm air than in cold air. Pressure decreases more rapidly with altitude in cold air than in warm air, & an altimeter that reads too high in cold air and too low in warm air. Density altitude is of concern because it reduces engine power & the lift of a wing. Density altitude can be determined by setting the altimeter to standard (29.92) & reading the altimeter.

● True altitude is the actual vertical distance above mean sea level, measured in feet. True altitude can be determined by setting the altimeter Kollsman window to the local altimeter to obtain the indicated true altitude. The indicated true altitude can then be converted to true altitude with the E-6B computer.
● Absolute altitude is the height above the local terrain. It is computed by subtracting terrain elevation from true altitude, or read directly from a Radar altimeter.

3.6.6.4..5 Clock:

DR requires not only prediction of flight time, but during flight, the determination of where the plane should be at any given time.

3.6.6.4.6. Thermometer (OAT):

Although a minor player in the process, TAS cannot be precisely determined without knowledge of OAT (outside air temperature) & the E-6B.

3.6.6.4.7 Avionics: Critical tools for specific types of Aero Navigation.

Early aircraft had no electrical systems, much less electronics. There were no airways; & very few airports, but most planes could operate out of farm pastures. When the post office needed air mail routes, they decided where they should be, but that was difficult for night flying. In 1919 they tried bonfires, which worked initially, but required a lot of manpower & coordination.

In 1921 they started installing towers, & by 1923 they had a transcontinental airway of towers located between 15 & 25 miles apart, & lighted beacons that were visible for 40 miles in good weather.

By 1927 the post office had over 4,000 miles of lighted airways, but the only weather information available was before take-off. Each tower had site numbers painted on it for daytime identification. The beacons flashed in a specific sequence at night so that pilots could determine their location by use of a "printed reference" which they carried. Each rotating beacon tower also incorporated 2 fixed lights; one pointed to each tower in the sequence on that Airway. An experimental communication radio was tested for ground to air with a range of 50 miles; & soon 150 miles.

Eventually manually tunable low frequency transmitters & receivers were developed for Aero Navigators for com & very limited directional information. Later a large round "Loop" provided directional information for Aero Navigation capability.

Charles Lindbergh could not justify carrying the weight of a radio that would be virtually useless on his historic May 1927 solo Atlantic crossing. A few years later he used Morse code with primitive early radio for communication on very long world-wide flights.

In 1929 the Federal Mail Service standardized on a 4 course Low Frequency Range system that transmitted an A & N in Morse code in each of 4 quadrants around each of a large series of transmitting stations. Aero Navigation system no. 8 gives a full description of the ingenious & fascinating Low Frequency Range system. When complete they had the safest, most reliable IFR Navigation & approach system in history. It revolutionized IFR flight. Enroute lateral precision was literally unexcelled.

Most low frequency Range Stations were decommissioned soon after the VOR OMNI Range system arrived on the scene, but a few still serve well in the 21st Century in the U.S. Some procedures, features, & even components of this now antiquated Aero Navigation system are still used routinely in IFR. Procedure turn techniques that were developed for the low frequency range are still used with little change for several other Aero Navigation systems. Some aspects of enroute operations were also maintained, & a few actual transmitters remain for some specific locations. The low frequency system was very poor, if not useless, in heavy electrical storm activity; much of which entails IFR conditions. It was, however, the standard for safety & practicality until the VOR OMNI Range system was introduced, with even greater capability, in the early 1950s

The VOR OMNI Range is still a valuable Aero Navigation system in the year 2009, & is expected to remain in use indefinitely. OMNI is discussed in detail in Aero Navigation system no.18. The earlier VOR receivers consisted of a crystal controlled transmitter that only offered 4 to 7 transmitting frequencies, & a tunable receiver that covered both the communication & navigation bands. The receiver used a "whistle stop" feature to facilitate precise tuning to the com frequencies installed. The navigation band was tuned to the approximate frequency listed on a Sectional chart while listening to the Morse code identifier for the desired VOR station. That Morse code identifier is still used, but the newer digital crystal mixer system is so precise that it is hardly necessary.

VOR transceivers soon began the integration of a simplex type communication transceiver with VOR nav receiver in a single compact package. Width was soon standardized at 6.25".

Until the 1970s all types of "radios" including Aero Navigation units were called radios. At that time the term "avionics" was introduced. It applied to all types of navigation & com "aircraft radios". Still later the term was expanded to include all electronics & most instruments in aviation. Each of these are discussed under the appropriate Aero Navigation system. The navigation systems have also grown in capability & complexity. Improving the capability usually resulted in more user friendly methods, but not always. The simplicity & accuracy of the LORAN in the mid 1980s, & the GPS in the mid 1990s are the epitome of this. Although both are based on vastly more complex equipment, & on technology that obviously did not exist at the dawn of aviation, both are the most accurate, as well as easiest to use. LORAN C is only practical for boats & aircraft because of the electronic ground field plane requirement. Airborne GPS receivers preceded the now popular & more familiar automotive & hiker types of GPS, & are more complex because of a variety of requirements that are unique to aviation. GPS, too, has limitations.

As progress was made, avionics added the capability of controlling the plane as well as Aero Navigation. The autopilot is, of course, a part of the avionics family. Autopilots can direct the plane to any desired heading. It can thus be set to a given magnetic heading. Or it can be directed to track an OMNI or fly a heading to "home in on" an OMNI station; or a radio beacon. An autopilot coupled to an ILS to automatically fly an instrument approach. It can use GPS or other Aero Navigation system to direct a plane to fly a "dog leg" (a track with an alter in the heading, such as around a mountain or controlled airspace, or to follow a shoreline). An autopilot is not directly an Aero Nav system, so is not discussed here.

Such systems are currently in use in unmanned aircraft, both **in combat** with cowardly terrorists, & to stop criminal illegal immigration across the border. At least as early as 2006 the FAA & manufacturers began discussing & seriously planning control systems which will literally perform all duties that are normally performed by a lightplane pilot. The pilot would simply hop in & watch it all happen. Not as much fun as doing it all without automation, but it has some merit. Each flight would be pre-programmed. FSS would communicate with each plane without pilot action to assure adequate separation from other traffic.

Modern avionics are controlled by Aero Navigators or pilots. Most pilots turn on all avionics before taxiing out for takeoff; to assure a valid magnetic deviation value (since each electrically operated item contributes to the magnetic deviation), as well as to confirm that all avionics are functional before plunging off into a bank of clouds.

Another little known factor that justifies this is a characteristic of electronic devices called "infant mortality power application shock" (from spikes). "Infant mortality" describes the increased likelihood of failure of new electronic equipment. Power application shock is also a factor in infant mortality, but is not limited to new avionics.

Electronic technicians frequently find intermittent electronic equipment problems by quickly cycling the power switch. So is the condition called "age deterioration"; electrolytic capacitors discharge beyond usability if left uncharged for an extended period of time. This condition is possible with some other electronic components, & thus equipment. The author's employer once bought each Engineer a new programmable engineering calculator. He advised all to burn them in, & never to turn them off during the day. One Engineer insisted in turning his off between uses. His was the only one that failed; & it failed in 1 week. Humidity can induce corrosion, so adds to the risk factor in allowing electronics & mechanical devices to remain idle. A TV or computer stored in a garage for a few years is very likely to fail to function. It is not prudent to turn Avionics off during flight, since "powering up" is more likely to cause failure if the cool down process has reached a critical point. The author has always tried to burn in electronics for several hours or days before turning it off the first time; thereafter operating it a minimum of once per week. He has experienced the merit of this technique play out with friends who left their computer or avionics off for too long; or who turned them off between each use, no matter how short the time. Turning electronics on too quickly after turning them off "can" induce failure. The "critical time" depends on the specific component & other unknowns, so the safest thing is to leave them on unless they will be left off for an extended period of time.

The same is true of the plane proper, as well as cars. Planes left idle for several months are much more likely to suffer from a wide assortment of failures. Engines build up a layer of rust on cylinder walls in about 3 days. Iron oxide (rust) is also an abrasive. Prudent pilots will try to avoid flying a plane after it was idle for a year. The author once required a "ferry permit" to return an "out of license" plane to home base after hurricane damage; after a 26 week period with no operation whatever. Ferry permits are very specific & limiting, so when he could only achieve approximately 50% power, he had the choice of applying for & waiting for a new Ferry Permit plus a very long time for repair, or taking off with reduced power. He was confident that the nature of the limitation would not result in engine failure, or additional loss of power. Fortunately he knew just how well (or poorly) it would perform, having made many take-offs from fields as high as 9,000 ft at very high temperature, & near max gross, where engine power & wing effectiveness were seriously degraded by the thinner air. Thus he knew this take-off & flight would be safe. It was, but not something he took lightly. The only cause for the low power was corrosion of 1 critical component from sitting idle for months.

Three Aero Navigation systems described in this series are so very new that few pilots know they exist. They literally make all other systems look primitive. They will not, however, result in decommissioning of most, if any, other Aero Navigation systems. At least 1 of the 3 is not practical for most lightplanes. Several other Aero Nav systems discussed are not practical for small lightplanes.

Some “avionics” devices are purely mechanical, but with the continued development of electronics, most were eventually offered as a mix, or entirely electronic. The term “glass cockpit” refers to large glass panels that usually have images typical of aircraft type instruments, as well as a moving map. The “glass cockpit” is similar to a TV or computer screen. Both large & small images are available to provide any desired info. As large aircraft grew in complexity, more information was required. As advances were made the need grew from the basic few instruments required for safe flight, & by the FAA (airspeed indicator, altimeter, compass, engine tachometer, etc) to a point when a typical airliner had 100 instruments in the cockpit. Some of these instruments required constant monitoring only briefly for specific periods. On take off the airspeed, & “engine condition” instruments are very important. For a single engine aircraft with fixed pitch prop & reciprocating engine, a the tachometer is relatively unimportant since the RPM increases as the aircraft accelerates. RPM is more of an indicator of proper power development. If rpm lags on a take-off vs. the norm for a specific speed, it’s time to abort the take-off. This is highly unlikely with the “bullet proof” Continental & Lycoming engines. An unexpected drop in RPM would most likely be detected audibly.

An occasional glance at the air speed indicator during initial climb-out, once trimmed for the climb, is adequate to assure the proper climb speed. The engine pre-take-off checklist should prove that all is well, so the only likely engine problem might be a minor reduction of power indicated by the tach; or oil pressure drop; either of which would probably indicate a serious problem. The compass would not be important during the ground roll, except as reference to set the manually adjustable DG (directional gyro). Actually, a competent pilot should be able to fly most small single reciprocating engine powered lightplanes from take-off to landing with all instruments covered. The author would not feel safe flying with a pilot who could not “fly by the seat of the pants”, but in a multi-engined turbojet or turbo prop powered plane it would be difficult to fly without full instrumentation. Fly by wire offers simulated stick forces, but may not be a perfect system. Conversely, the miraculous landing on the Hudson River would not likely have been successful had “Sully” not been such an outstanding pilot, & most likely “capable” of flying “by-the-seat-of-his-pants”, though he must have referred to instruments. Modern jet fighters & airliners are not flown by manual forces exerted on the control surfaces. Even though the forces are artificial, they do not simulate that feel of control forces in a lightplane. Thus flying by feel is more difficult than in a lightplane.

Likewise, the sound is biased if engines actually failed, so it would be difficult to interpret & fly by sound, or the-seat-of-the-pants. Modern lightplanes can be flown, if necessary, by the response to control movement, sound of the slipstream, or the feel of the stick forces. In Sully's case, aircraft response to control movement may have been an indicator & meaningful only to an exceptional pilot like Sully; with such large, heavy planes.

Full power is normally applied to reciprocated engine / prop powered planes for take-off. A turbine engine is rarely operated at full power during T.O., since it could cause either excessive torque, or turbine inlet temperature (TIT), depending on conditions; either of which could quickly destroy the engine. During climb-out, power, airspeed, & heading must be monitored. In VFR & level flight (visual flight rules; when the pilot can see the horizon), most instruments are used only for reference. In climbing or descending turns, & certainly under IFR conditions, all are important, but the artificial horizon & directional gyro are the most critical. The computer controlled glass cockpit allows the pilot to improve the visibility of critical instruments while lessening the distraction of less important items. In such sophisticated planes instruments sound alarms if out of the normal operation range.

The pilot can change the dominant instruments as the need arises. The glass cockpit significantly reduces pilot workload, & improves safety. Conversely, the glass cockpit is much less reliable than the century old mechanical instruments. An Airbus actually landed in the U.S. with no working avionics when it lost its glass cockpit, & even communication radios. The pilot obviously was capable of, & did “fly & land by the seat of his pants”. The large jets, like modern fighters, use boosted controls, which attempt to simulate aerodynamic control forces to aid the pilot in flying by feel; without instruments. It is quite difficult to fly these large fast planes by the seat-of-the-pants. Since the weather was VFR (visual flight rules, landing was possible by visual references on the ground) an instrument approach was not required. Under IFR conditions the result might well have been catastrophic. The Airbus has experienced several dozen cases of total failure of glass cockpits. It is shocking that it had so little redundancy, & enough failures to preclude an instrument approach.

Redundancy, even in light aircraft, is normally adequate to permit a safe landing, even in the event of multiple avionics failures. Elsewhere in this course the author explains how to fly under IFR conditions with virtually no Avionics. He has experienced the benefits of redundancy on 2 occasions. One on a flight from Houston to Gallup, New Mexico, his pilot-wife & he noticed at the same instant, an instability of the vacuum powered gyro horizon (A.G.; attitude gyro), & immediately looked at the vacuum gage. With the vacuum below spec, it was necessary to resort to the “primary panel”; so they flew the next 500 miles engulfed in clouds (knowing that the weather was VFR near Roswell). The expectation by the FAA is to land at the earliest convenient location upon loss of primary gyros, but with the redundancy described elsewhere in this course, including the unique zero gyro IFR, continuation on primary panel was quite safe.

With neither the D.G. nor A.G. (directional gyro & gyro horizon), a safe approach & landing could have been made relying only on the electric powered gyro of the T&B instrument; flying the primary panel, although it would have required a little more attention, & a somewhat higher skill level. Redundancy was again proven invaluable when, on another occasion, the boom microphone failed at a time when he'd left his spare microphone at home. Thanks to a unique form of redundancy, he was able to rely on the transponder "squawk" feature to communicate with flight controllers, & locate & shoot an instrument approach into an unfamiliar airport in Arkansas. The transponder communication feature was used several times in the process. Since he could hear the controllers they simply instructed to "squawk ident" if he had enough fuel. Did he have a specific "approach plate" for the nearby airport that they selected for him? It was very easy to communicate with "yes" or "no" answers. Depress the squawk button for yes; failure to squawk meant the answer would have been no. The experience was indeed rewarding, as well as an excellent confidence builder.

The Aero Navigator must understand the function & output of all instruments & avionics, as well as the impact of winds & the atmosphere, at all altitudes, on Aero Navigation. Being familiar with options available to safely handle emergencies is vital to safe & confident flight.

3.6.6.4.8 See Appendix D for additional info on above tools & Additional Pertinent Tools, Instruments & Avionics not mentioned above.

4 Aero Navigation Systems

4.1 Overland Navigation System No. 1: A Recently Discovered 5,000 Year Old Overland Navigation System

Is it true that there is evidence of a highly accurate 5,000 Year Old navigation system in England? There certainly seems to be. A British historian named Tom Brooks used a modern GPS system to prove his theory. If his theory is valid, it proves that the discovery of geometry predated the accepted claims that the Greeks were credited with this achievement. If so it also proves that ancient man was far more advanced technically than previously thought.

He also claims that the well known source of his discovery was the world's largest Civil Engineering project. Per Mr. Brooks, Stonehenge is a portion of that massive seemingly impossible Civil Engineering project. He offers no explanation as to the method used to achieve astonishing accuracy of this superb navigational system; or possibly it should be called a surveying system. That accuracy was typically better than 100 ft.

The large series consists of over 1,500 historical sites that wind across England & Wales; presumably selecting the most practical routes. They include stone monuments that have a few things in common. Most were erected atop high hills. Each includes isosceles triangles with 2 precisely equal length sides. Each such triangle points to an adjacent triangle; some as far as 100 miles apart. Apparently each monument initially had a nearby settlement. The object, per Mr. Brooks, was to facilitate cross country navigation for commerce, etc.

Obviously anything as heavy as the massive stones of Stonehenge are not applicable to flying, but it seemed to justify a place in this document. Other ancient forms of Navigation are included since they were actually adapted to Aero Nav. Two other non Aero Nav systems that are included are closely related to Aero Nav.

Note: Around 2005 a retired American construction worker demonstrated how one man could handle such massive stones when he single handedly moved & then raised a similar sized stone from the horizontal to the vertical.

4.2 Aero Navigation Systems No. 2: Dead Reckoning (DR) including Airplot

4.2.1 Background:

Dead reckoning, of sorts, was used by the earliest of man, just walking to points of interest; or finding his way home. The earliest travel of any type must have used some form of DR, even without the benefits of maps, compass, clock or any indication of speed. To walk from a fishing spot or deer trail, he needed to know the direction & time to travel; so he'd be safer from night predators in some cases, after the hunt. They may have even been observant enough to apply a little celestial; at least the sun position vs. daylight remaining. DR was used, even though mostly by guesswork, by sailors. They had learned a little about wind & ocean currents, so applied drift correction just as Aero Navigators must.

Knowledge of the solar system, & the development of a compass that was functional with marine motions offered major advances to Marine Navigation. Drivers use a form of DR to determine how long a road trip will take. Boy scouts use it for Orienteering. Scouts use maps & compass to travel on foot between 2 specified points; usually on unfamiliar terrain, & with intermediate reference points along a devious route.

DR for Aero Nav evolved from rough guesses & crude maps to precision flight planning including wind correction. Development of special items like the Weems plotter & E-6B added significantly to the practicality, effectiveness & user friendliness of DR.

Aside from marine use, Aero Navigation is the only modern day application where the use of DR is actually critical; & used frequently. Dead reckoning is an essential Aero Navigation "system" for the pre-flight in that it must always precede any XC (cross country) flight. Barring avionics that requires programming (DCE, LORAN, or GPS) before any flight (if not previously programmed), the only trip preflight activity required for an oft repeated flight is the application of forecast W/V. Pre-flight does, however, include chart preparation, if a new route is to be flown, or if charts that are available are out of date.

4.2.2 Theory:

DR is based on math, including trigonometry. Time, distance, speed & direction are the major concerns in DR. Math is easy with any Engineering calculator, but trig is not convenient in flight on such a calculator. The manually manipulated E-6B facilitates the wind vector computation & is necessary to establish the aircraft heading required to achieve the desired true course. An Aero Navigator should also compute all aspects of any flight before TO.

4.2.3 Accuracy & Efficiency:

The accuracy could be well under 1 mile on short flights if the Aero Navigator is able to hold his heading precisely, & knows the actual wind velocity. Serious errors are possible in the actual applications, & long flights. Realistically 5 miles per 60 miles of flight distance is likely. System 10, 11, 12, 25, & 26 explain how to measurably reduce the error of DR without a means of obtaining fixes.

DR is efficient in that DR flights can be direct; avoid deviations to decrease distance, & thus flight time.

4.2.4 Application:

4.2.4.1 Applications of DR
● Preflight is accomplished by DR, a stand-alone Aero Navigation system, used with all Aero Nav systems
● In Flight position information
● Knowledge of DR is essential for all types of Aero Navigation

4.2.4.1.1 Basic DR consists of:
● Determining the distance & direction from departure point to destination.
● A Weems plotter permits determining the TC & distance.
● By the simple math problem of dividing distance by aircraft speed to predict flight time becomes slightly more involved when a direct head or tailwind is forecast, which are even rarer than zero wind.. The most likely wind is from an angle (RB) other than "the normal" (90°) crosswind. Drift & GS impact is no longer intuitive. Neither drift angle nor GS are obvious; but require vector analysis.
● Applying TAS & wind velocity to an E-6B or equivalent provides drift angle, GS, & total flight time.

4.2.4.1.2 Left as a stand-alone Aero Navigation system DR is limited in accuracy, practicality, & general usefulness, but it is absolutely an essential part of virtually all Aero Navigation systems. A flight can be accomplished successfully by use of pure DR, if the forecast W/V & other errors are not excessive. A major wind shift could result in failure to reach the destination, or flying past it without seeing it, if too far off course.

A less obvious complication, as with all Aero Nav systems, is the requirement for conversion from IAS (indicated air speed) to TAS (true airspeed). This conversion is nearly instantaneously accomplished by use of the E-6B or equivalent (electronic). It would require a complex computer program to perform this conversion with a programmable calculator or computer.

4.2.4.1.3 The pertinent parameters used in DR are listed & briefly defined:

● AP (Air Position; also called airplot) is a valid, useful parameter that is not often discussed by non professional Aero Navigators. It treats a flight without regard for wind. After a specific period of time a wind vector is applied to correct the air position to a presumed actual position. The TH & TAS are plotted on the chart as soon as TH changes; fly TH for 6 minutes at 180 kts would be plotted at TH & 18 NM. Repeat as often as necessary. After altering ceases, plot W/V for time of all alters to find the best DR position. This can also be performed on the E-6B. Airplot is most useful when the plane must fly an erratic flight path such as dodging severe weather, or reducing the risk of being hit by flak in wartime. Airplot may be used while flying with any other Aero Nav system.
● Course Line is the desired horizontal flight direction & distance of the aircraft.
● GS (Ground Speed) is the speed of the aircraft over the ground. It may be expressed in knots or mph (statute miles per hour).
● TAS (Indicated air speed) is as stated, airspeed indicator reading.
● TAS (True Airspeed) is the rate of motion of an aircraft through the air. Because the air mass is rarely static, the wind speed impacts the GS.
● TC (True Course) is the desired horizontal flight direction over the earth, expressed in angular units measured clockwise from true North (000° through 360°) to the longitudinal axis of the aircraft.
● TH (True Heading) is the horizontal direction in which an aircraft is pointed. Like TC, it is angle measured clockwise from true North.
● TR (Track) is the horizontal component of the actual flight path over the earth. Track rarely precisely coincides with the TC. The difference between track & TH is wind induced drift. Any variance is the result of an inability to precisely anticipate in-flight conditions.
● DR (Dead Reckoning) is an essential Aero Navigation system without which neither preflight planning nor Aero Navigation can be accomplished. DR is based on mathematics & trigonometry computations to establish all pertinent parameters regarding a flight between any 2 points in an environment that includes winds. This includes IAS, TAS, W/V, GS, TC, MC, TH, MH, CH, & time. DR is nominally accomplished without any navaid to establish extent of errors that result from "real world" deviations from plans. It is also defined as the position obtained by applying wind effect to the true heading and true airspeed of the aircraft. A DR position estimates the progress that “should have been made” since the previous fix.
● FIX is a term used to describe a generally accurate actual position of an aircraft as determined by an Aero Navigation system such as map reading.

4.2.4.2 Direction of Flight:

Certainly an airplane must be “directed” from departure point to destination. It may not be so obvious that this requires several different methods of establishing “direction”. But just what is meant by the term direction?

Direction is stated in degrees; as measured clockwise from true North, but the Aero Navigator must apply several factors that alter what the Aero Navigator must read on his compass to follow the desired TC:
● TC as mentioned above is the ground track.
● Wind induced drift requires a correction to the TH
● TH (true heading) is the heading from true North
● Magnetic variation, is indicated for each location on a Sectional as shown in Fig 5, & illustrated in Fig 9B. Magnetic variation correction must be applied to obtain MH (magnetic heading). See paragraph 4.2.4.2.2 below for additional details.
. ● A magnetic deviation correction results from EMI within the plane. The magnetic deviation correction informs the Aero Navigator & pilot of the CH (compass heading) to fly to maintain the desired MH. This information is provided per Fig 10 for a specific plane, & discussed in greater detail in paragraph 4.2.4.2.3.

: W/V (wind velocity = direction & speed) is a critical influence on all flights, & thus to Aero Navigation. Every Engineer has an excellent grasp of the simple Vector. The “wind vector” is used to determine the effect that W/V has on a plane. For typical non-technical Aero Navigation students, an elementary explanation suggests that they assume that the airplane travels with no wind for 1 hour; & thus moves at a rate equal to the true air speed in miles, “after which” the wind drifts the plane, as it drifts like a free balloon, for another hour; at the speed of the wind.

4.2.4.2.1 Wind Drift Correction:

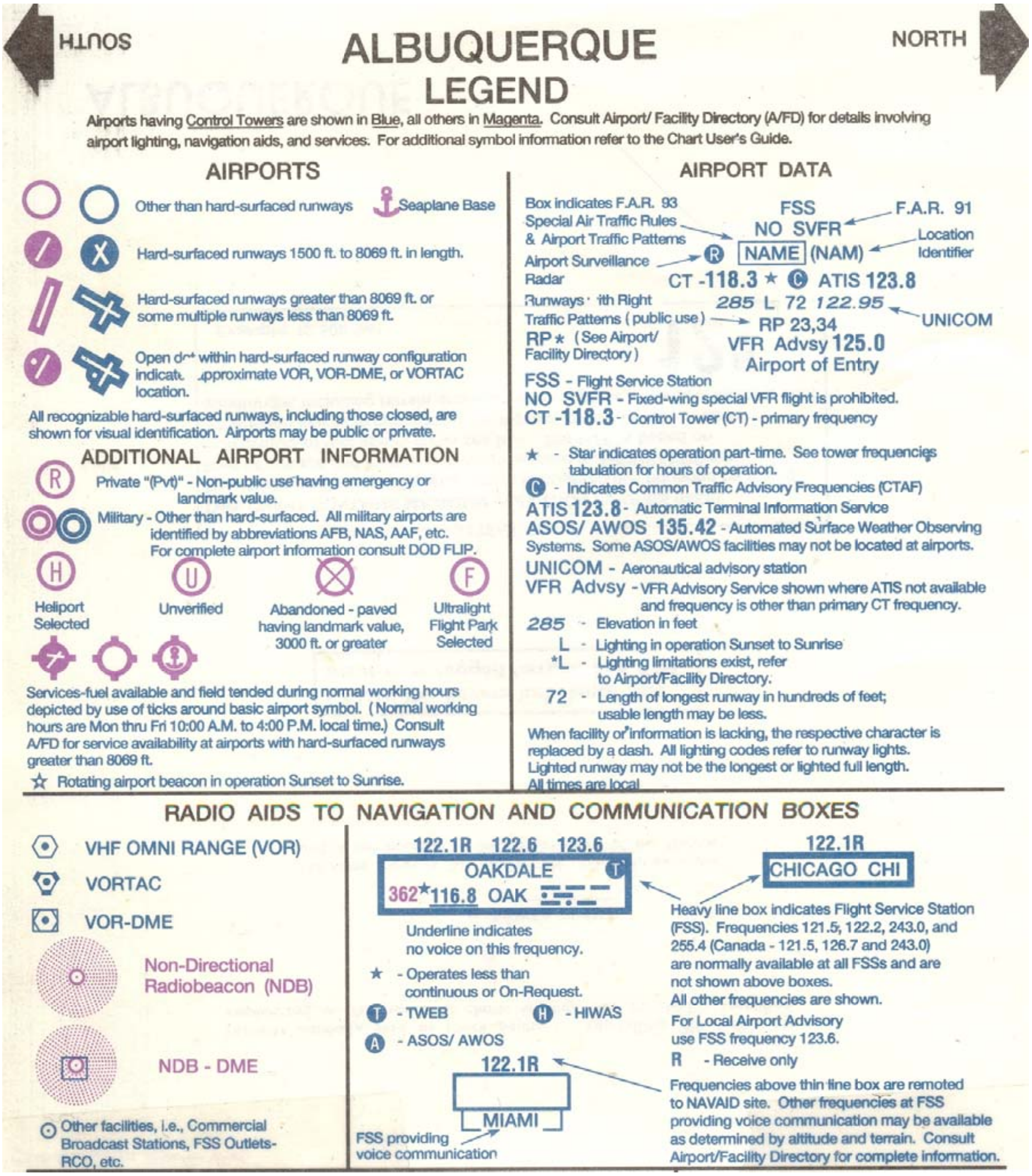

Fig 9A - Sectional Chart Legend; Key to Symbols; Top Half

The resultant vector thus provides the actual TC – GS (true course – ground speed) Vector over the ground. A wind vector could be drawn directly on a Sectional chart if a large table is available; before flight, but not easily during flight in a lightplane. Alternately, a tablet, preferably with grid lines, could be used to facilitate drawing to scale. Fortunately there are more convenient wind vector solution methods. These are discussed later.

After obtaining the drift angle & direction (left or right), as well as ground speed, it is a simple matter to divide the actual course distance by the computed GS to determine the duration of the flight. Incidentally, a hot air balloon can be quite a joy to fly; actually exciting. "Control" response (burner "turn on") is reminiscent of the J-3 Cub (a wonderful little plane, but very slow) with a loose bungee on the elevator control, so that elevator response would be immensely slow.

Additional details on wind effects follows in paragraph 4.2.4.3.2.2.

4.2.4.2.2 Magnetic Variation Correction:

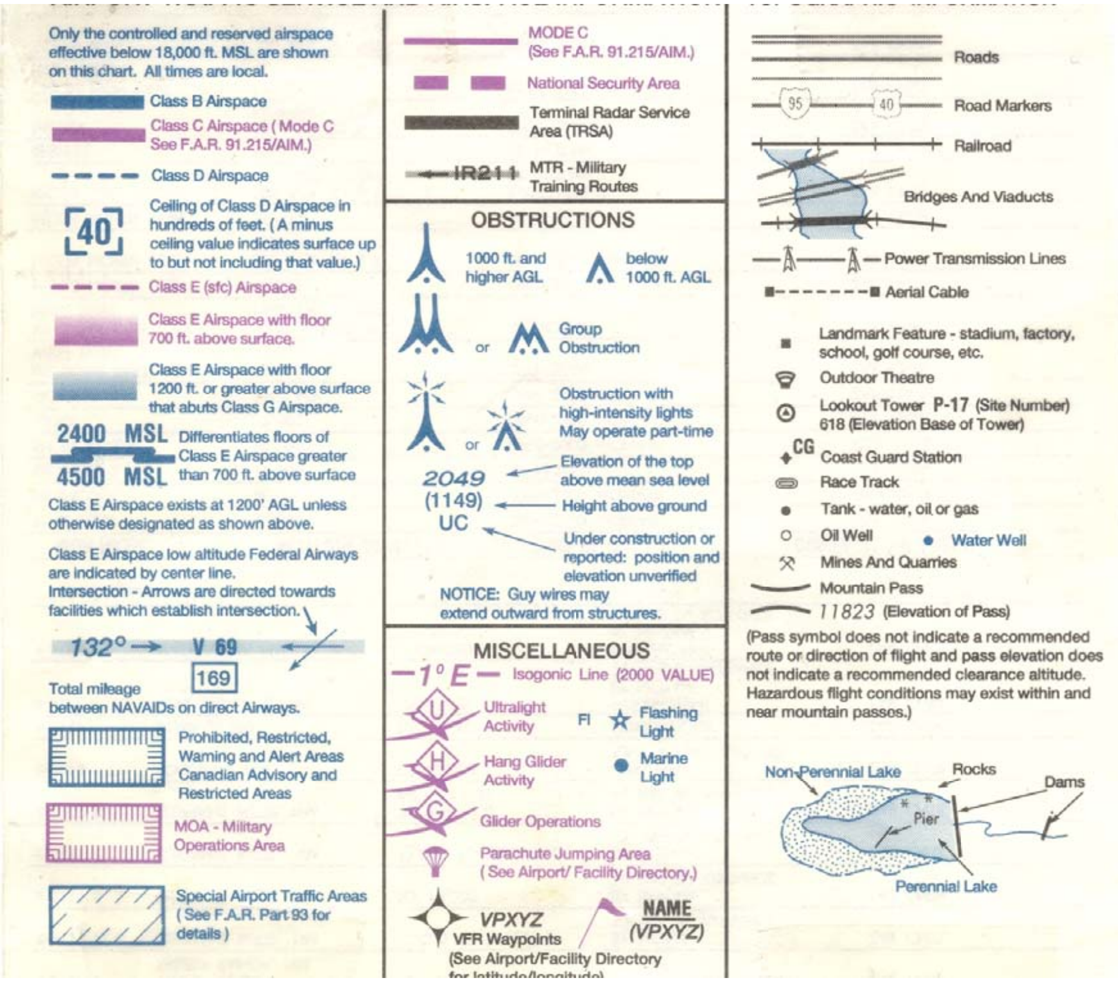

Fig 9B - Sectional Chart Legend; Key to Symbols; Bottom Half

Compass Correction			
For	Steer	For	Steer
360	003	180	181
030	034	210	210
060	065	240	238
090	094	270	269
120	123	300	297
150	152	330	329

Fig 10: The "Compass Card" (table) Details Magnetic Deviation Correction

Another important issue in DR, & all other Aero Navigation, is correcting for magnetic variation. A general worldwide look at magnetic variation is illustrated on Fig 7**,** which was discussed earlier. Magnetic variation results primarily from the fact that the magnetic North pole is not coincident with the true North pole. Local magnetic variation is documented on all Sectionals, as illustrated in Fig 5**.** Local variation is primarily caused by the relative displacement between magnetic & true North poles. Additional components of magnetic variation result from unique magnetic influences within the earth, such as iron ore deposits. These further reduce the regularity of the Isogonic Variation lines. These 2 components are not independently distinguishable by either the Aero Navigator or the compass, so a combination of the 2 "comprise" the "magnetic variation". Nor does the Aero Navigator care what causes the specific magnetic variation value.

Magnetic variation depends only on the "location" of the aircraft on the earth, without regard for orientation (aircraft heading). It is "independent of the heading" of the plane. Conversely, magnetic deviation, which is discussed below, varies with heading; not location on the earth. Both deviation & variation must, however, be determined & corrected for.

Each Sectional chart has a series of widely spaced, "randomly shaped, gently curving" dashed magnetic Isogonic lines that represent magnetic variation. The shape of the line is irrelevant. It simply traces out one specific value of variation at various points along the chart. Comparing charts that were printed several years apart may surprise the viewer since the magnetic variation actually changes in time. Since magnetic variation impacts the compass reading, & the compass is vital to Navigation, all Sectional charts are imprinted with the local value of magnetic variation.

In Fig 5 the dashed magnetic variation line that passes to the right of Houston Hobby airport indicates a magnetic variation of 4.5°E (4° 30' E). Fig 12 shows another. Variation is given on charts in degrees "East or West". The "sign" of the angular variation value is determined by the limerick "East is Least, & West is Best". "East" variation suggests subtracting East variation from the T.C. (True Course), to obtain magnetic course. Thus a true course of North (0° or 360°) will require a 355.5° magnetic course; as established after subtracting 4.5° from 360°. The 4° 30' E was placed just above the compass rose that surrounds Hobby (HOU) airport.. The Houston Hobby airport symbol is the round solid blue circle enclosing 4 white "runway configuration" lines. This & other symbols are shown on the copy of the "legend" section of an Albuquerque Sectional chart; Fig 9 (A & B). If an Aero Navigator desires to fly in the vicinity of Houston Hobby airport, he must apply the 4.5° magnetic deviation (fig 5). To fly a true course of 360°, with a 4.5°E variation, assuming no cross wind component, the pilot should fly 360° **-** 4.5° (or 4° 30' E) = 355.5 (or 355° 30').

Note that magnetic compasses usually only have a resolution (minor division spacing) of 5°. Add to the inaccuracy the considerable swing, & it is obvious that flying within 2° of the desired heading would be difficult. Thus to the Aero Navigator variation is not so precise to justify 30 arc minute resolution. The magnetic variation is verified by the printed OMNI compass rose that is centered on Hobby airport, since the true magnetic heading of 355° points vertically; North. OMNIs provide a signal that is based on magnetic North instead of true North, so 360° (0°) on the OMNI compass rose is shifted to the right of true North; in this case by 4.5°. Variation is included in the OMNI system orientation to simplify flying with the OMNI.

It is not necessary to correct for magnetic variation. If using the OMNI compass rose, the course drawn on the charts must be referenced to the OMNI compass rose, instead of the parallels or meridians, for measuring the course, to correct for magnetic variation. If the meridians or parallels are used for reference, then a magnetic variation correction must be made.

See, for example, the blue arrow pointing in the direction of 284°, & annotated with the 284°, just to the left of the Hobby airport symbol on the above referenced chart.

Unfortunately, the winds aloft are always reported relative to true north. Surface winds are given relative to magnetic North. Treatment of wind effects, course lines, & variation correction are given below, & referenced & discussed in several other courses in this series. Note that the chart makers simplify course selection for pilots by printing MC of airways for the routes from the VORs. The origin of this arrow is the center of the VOR (VHF OMNI Range) point of transmission that is located on Hobby Airport; not necessarily the geographic center of the airport.

4.2.4.2.3 Magnetic Deviation Correction:

Magnetic deviation is yet another variable that must be corrected for. It is caused by magnetic influences within the aircraft, including engine ignition, generator-alternator, assorted electronic devices, & even wiring within the plane. Thus the deviation correction must be accounted for to obtain the correct compass heading (CH), so that the plane may be "steered" over the desired track across the ground.

Magnetic deviation is different for each aircraft, & actually for each heading. It may also change as various pieces of avionics are turned on or off.

A "compass swing" allows one to determine deviation values for a variety of compass headings. Fig 10 illustrates "for & steer values" for a series of headings for 1 specific aircraft. On this deviation card "For 270° Steer 268°", alerts the pilot of the heading to steer for a desired magnetic heading of 270°. The varying differences between "for" & "steer" values indicates that deviation is one of the variables. The magnetic deviation must be calibrated by placing the aircraft over a compass rose which may be painted on the airport ramp, or by using, as the author occasionally did, a master compass that is itself calibrated, & fitted with a “sight” to permit alignment of the master compass with the longitudinal centerline of the aircraft.

The compass swing requires 2 people. One person inside of the aircraft monitors the engine & avionics that must operate for a valid swing, & another must stand in front of, or behind the plane to direct the plane occupant as headings are changed. Someone must obviously document the compass heading vs. the “noted” MH (magnetic heading). Communication is necessary, of course, regarding each heading. If the plane includes more than 1 magnetic compass, such as the author’s remote compass along with the mandatory self powered small magnetic compass, 2 compass cards are necessary.

4.2.4.3 Preflight Planning & Flying with DR

4.2.4.3.1 Features of The Weems Plotter

The Weems Plotter facilitates measurements of distance & direction of a desired route on a Sectional. The Weems plotter was designed to simplify course measurements for preflight planning as well in flight tracking activities. Fig 11

The first step in conducting a preflight using "dead reckoning” is to determine the route; distance & T.C. (true course; also known as ground track) between the departure point & destination. Distance is generally determined by measuring in NM (or statute miles) by any of several means, including the mileage scale of a Weems plotter. The direction that he must fly is also determined by use of a Weems plotter as shown in Fig 11. The Weems plotter is used to measure TC as the angle from true North, by reference to parallels of latitude, which appear as horizontal lines on a Sectional chart.

The parallels are, of course, not great circles, but always run directly E – W. Meridians are only parallel at the equator, & taper together toward the Poles. Meridians do run N-S. Meridians should only be used, if unavoidable, to establish TC. The protractor function of the plotter is less important if the OMNI compass rose on Sectionals is utilized, as is still most common, even though the GPS has displaced much of the actual Navigation by OMNI.

Note that Fig 11 illustrates details on this important Aero Navigation tool. The long shaded arrow heads point to, & identify the purpose of specific features of the Weems plotter. The several parallel lines on the linear portion facilitate alignment with a course line while positioning the protractor scale on a parallel. Since all meridians taper toward a single point at the North pole they should be used to measure course direction only if parallels are unusable.

Although the “protractor” portion may be read directly along a parallel of longitude, calibrations are also provided for courses that are too close to East-West to be used in this manner. The series of parallel lines facilitate alignment with parallels that may be well away from the course line. The small angular scale near the 90° major index facilitate reading courses near 180° or 360° by reference to the parallels of latitude. Like the old fashioned manual Engineering slide rules, the user must visualize the proper values (course angle) to prevent flying off in the wrong direction; 90° or 180° off-course. This may sound unlikely, but at night, or even under heavy cloud cover, there is nothing other than aircraft instruments to guide the Aero Navigator on his actual true course or TH. Flying over the farm lands of the Midwest, ”section Lines” are oriented N-S & E-W, which facilitates heading choice & hold. In some parts of the U.S., Canada & most other countries, no such lines exist. A casual joy ride has resulted in more than 1 lost Aero Navigator-pilot; especially where there are no section lines, such as over the beautiful Southwestern deserts.

The Weems plotter linear scales are calibrated for typical Aero Navigation charts. Both Sectionals & WAC charts are represented on these scales. WAC charts are most often used for high speed aircraft, since they cover a larger portion of the earth’s surface, & rely very little on map reading.

DR is the most basic form of Aero Navigation. It serves 3 basic critical functions:
●● Preflight Planning DR:
● It permits creating a flight plan with inputs of length of track, TC & W/V as inputs, & outputs of proper TH, & predicted drift, GS, & time enroute - ETA.
●● Pure DR Enroute:
● It calls for complying with preflight & steering in a known direction, climbing at optimum IAS & GS, & cruising at a known speed, & altitude per preflight.
● It requires computing progress at any time; or multiple predetermined times based on forecast W/V & actual IAS, altitude & temperature; converted to TAS.
● It requires computing progress at any time; or multiple predetermined times based on updated W/V, if applicable, & actual IAS, altitude & temperature; converted to TAS.

●● DR in Support of Any Other Aero Nav System:
● It calls for complying with preflight & steering in a known direction, climbing at optimum IAS & GS, & cruising at a known speed, & altitude per preflight, with TH changes based on Aero Nav system position or track information to maintain intended TC.
● It calls for computing progress at any time; or predetermined times based on forecast W/V & actual IAS, altitude & temperature; converted to TAS. a computed time to reach a destination with no other Navigation information; to be certain that he has a fall-back in the event that his Aero Nav systems all fail.
● It calls for updating DR information based on any W/V updates received.
● It calls for remaining on course & obtaining frequent fixes by use of the primary Aero Navigation system, & if practical, by another 1 or 2 Aero Navigation systems, & updating GS, time to destination (& ETA).

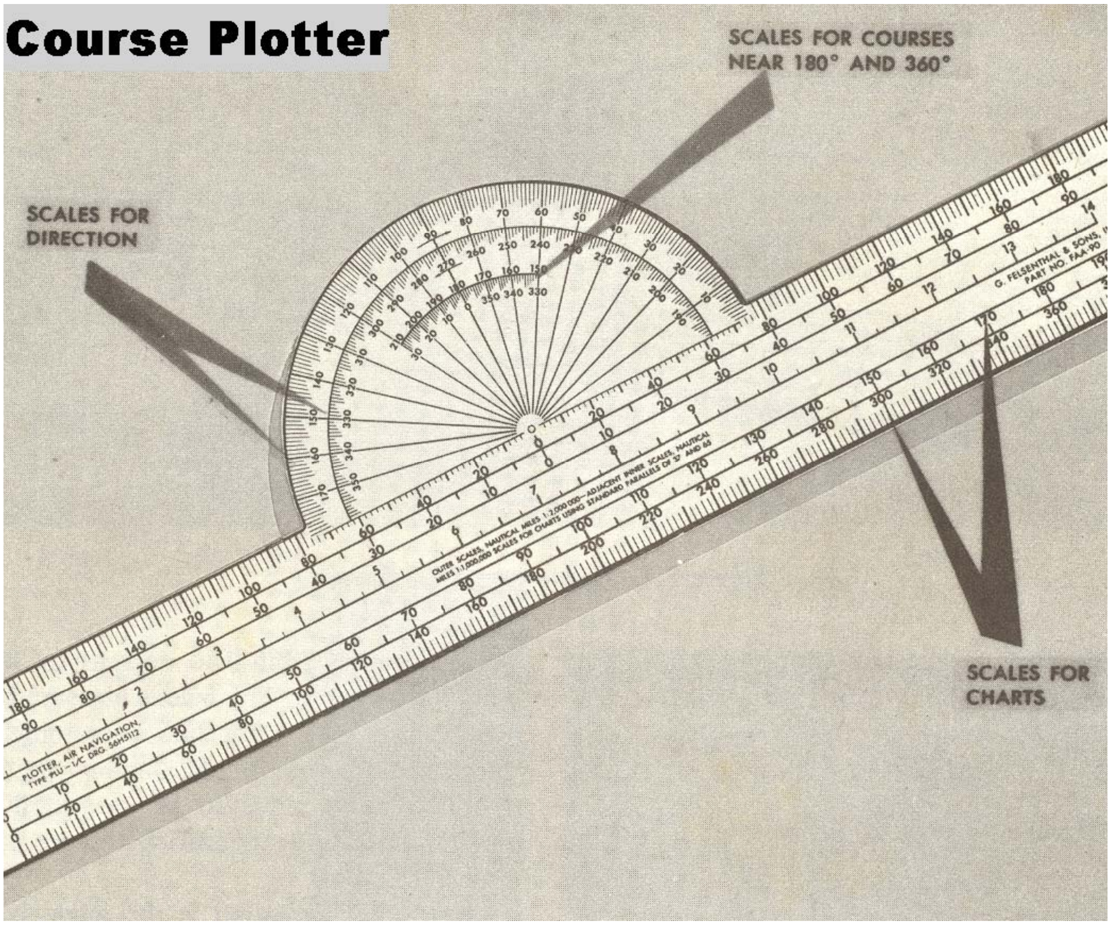

Fig 11 - Weems Plotter

DR flight example: Fly 100 mph for 2 hours, heading straight North & arrive 200 miles North of departure point, unless wind deflects the direction of flight East or West. DR demands determination of wind effect as well as TAS impact.

Both distance & T.C. angle are generally determined by measuring a Sectional chart by use of the mileage, & angular scales of a Weems plotter; per Fig 11. Also see Fig 12 for the distance scale on a desolate area on the Albuquerque Sectional chart (desolate, but beautiful; & ABQ is certainly also 1 of the most beautiful & advanced cities in the U.S.). In terms of the airport elevations, Albuquerque has an elevation of 5352 ft above MSL (mean sea level), vs. 6345' for Santa Fe which is only 80 miles North. New Mexico has numerous airports located at elevations above that of Denver. Denver enjoys the claim of being the mile high city, but the Denver airport barely qualifies with an elevation of only 5341'.

The airways on these charts are very complete & detailed. The chart makers even simplify course selection for pilots by printing the MC (magnetic course) of airways for the routes between the VORs.

This chart illustrates another example of a magnetic bearing & MC with 258° for airway V94 departing Deming VOR to the West. Also see the 236° for airway V202 departing Deming VOR to the West-South-West. Note also the dashed 11°E magnetic variation line passing thru Silver City. Deming, New Mexico is a very small town, not far West of the White

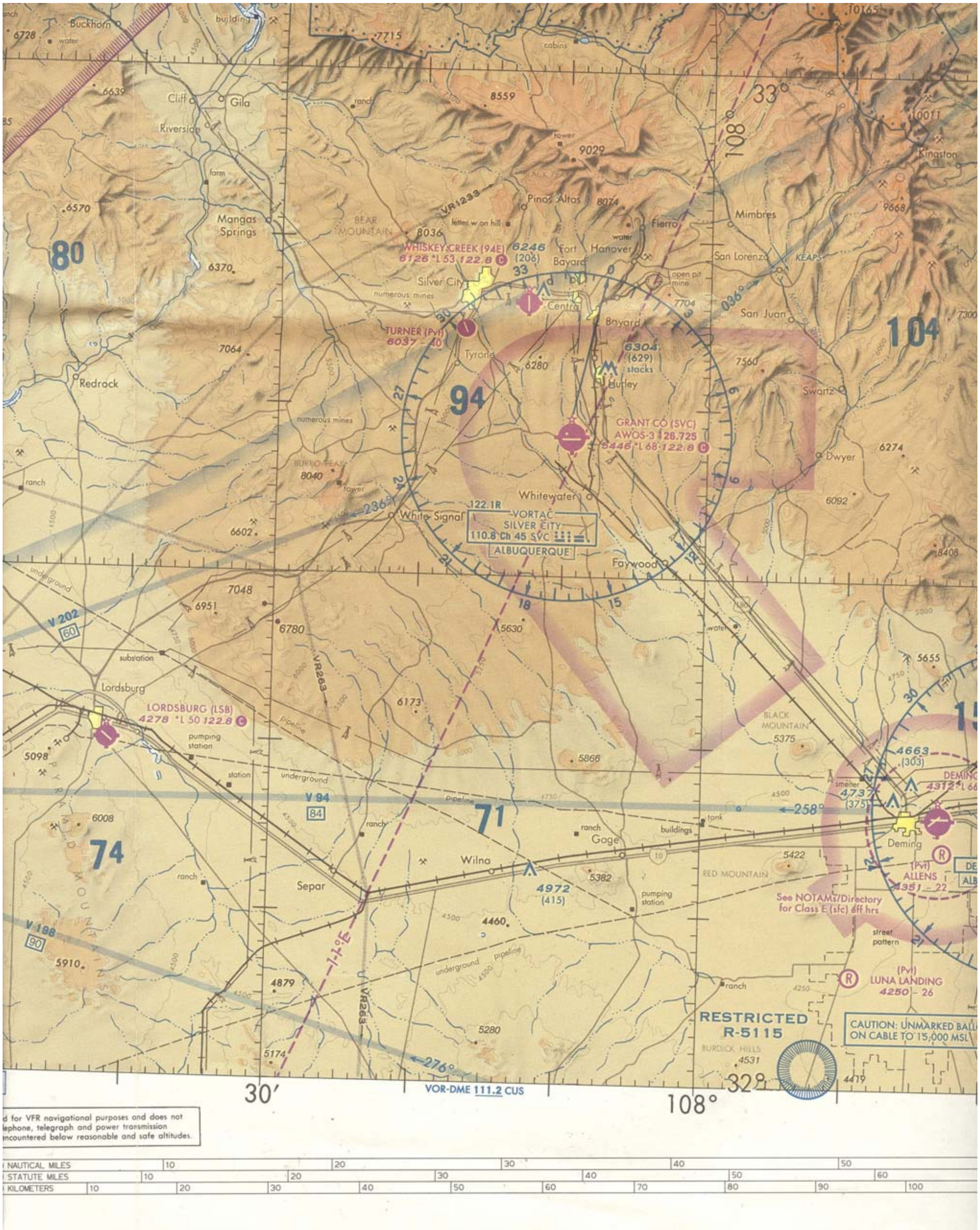

Fig 12 - Mileage Scale on Albuquerque Sectional Chart

Sands Missile Range, & El Paso, on Interstate highway I10 . It has a large airport, & a museum that seemed to the author & his wife to nearly rival the Louvre & the Smithsonian.

Silver City, NM is near the fascinating Gila Cliff Dwellings, & the "Exciting" Catwalk; which offers a fascinating & enchanting view on a safe, but long climb over beautiful rapids, & up spell-binding cliffs, on which parts of the Catwalk hangs. Built for a mining operation during the 1800s, it is truly an exciting, but isolated park to visit. This is one of literally millions of attractions that are a short hop from any airport in the U.S. The author his entire family once flew from La Porte TX to the Grand Canyon, Disneyland, numerous sights along the West coast, to the far NW corner of the U.S., to Mount Rushmore, Missouri, & back to La Porte in one week. They saw more from the air than on the ground, & still made many interesting stops along the way, even considering several hours of IFR flying.

Note that an alternative to the Weems plotter for measuring distance on a Sectional chart is to transfer distance from the course line on the chart to the mileage scale on bottom of Sectional by use of a pair of Engineering (drafting) or machinist's calipers. Another handy alternative is to trim the mileage scale off of an old chart & glue it to a yard stick, or for a more professional look, a 3 ft long Engineering scale.

The author does prefer to draw the course line; or as a minimum to mark "hash marks" across the course line in 50, or 100 mile increments; 10 mile near crucial fixes or waypoints. Such mile markers could conceivably be important in the event of Avionics failures even if flying IFR; or if Navigating with GPS or LORAN; a safety measure that also adds to convenience for Aero Navigation. Anything that an Aero Navigator can do to improve readiness for unexpected changes or emergencies in flight is well worth the effort, even though the likelihood of an in-flight emergency is remote.

Note that the upper mileage scale on the Sectional chart is calibrated in nautical miles; with the center scale in statute miles, & the lowest, which is virtually never used in the U.S.; in kilometers.

Although there are more convenient ways to solve the "wind vector triangle", a manual solution facilitates comprehension; not generally a concern for Engineers.

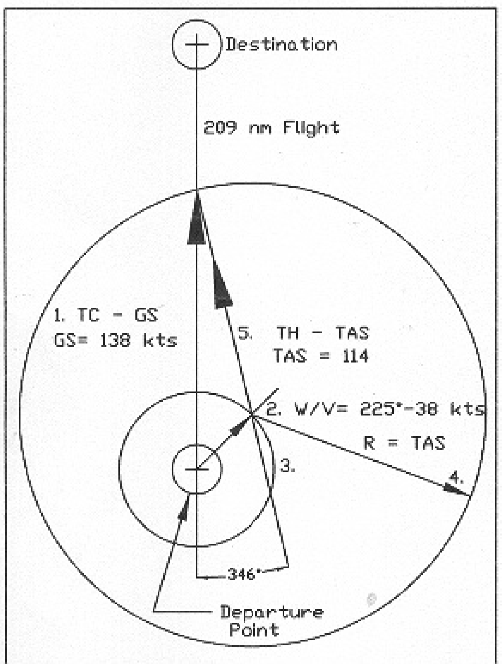

Fig 13: ACAD or Hand Drawn Wind Vector

A wind triangle solution is necessary for the application of DR, or any other type of Aero Navigation. It could be drawn manually; directly on a Sectional chart, on grid paper, or using ACAD as shown on Fig 13. The sequence of actions in this case are numbered in Fig 13:

1. Draw a line from the departure airport to the destination airport, & measure course & distance. In this case, the TC is 360°; distance is 209 NM (nautical miles). Plotting a W/V is most practical if treated as a 1 hour flight since wind is given in knots; NM per hour.
2. Draw the wind vector downwind (up from departure point) at an angle of 45° for 225/38 wind velocity.
3. Draw a circle with 38 NM radius across the wind direction line to establish the length of the wind vector. The head of the wind vector is at the intersection of the wind direction line & the wind speed circle.
4. Draw a circle with its center at the head of the wind vector, & a radius equal to the TAS (true air speed) of the plane.

5. Draw the TAS - TH flight vector line between the head of the wind vector & the intersection of the TC line with the TAS circle.

Finally measure the angle from tail to head of the TAS - TH vector relative to true North to determine the required TH & measure the distance from the departure airport to the intersection of the TC line with the TAS circle for the GS vector.

Instruments (magnetic compass, DG, & instruments like the ADF, with a "compass rose" scale) are typically marked with minor divisions of 5° (very rarely 2° minor divisions), so to claim a 1° accuracy is indeed a stretch. Even estimating heading to ±2° is generally questionable. Add to that the inherent occasional turbulence, & the resulting "swing" about the aircraft longitudinal (yaw) axis, & it is obvious that headings are certainly not always held precisely. Erratic movement of a magnetic compass is enormous compared with reading errors on most analog Engineering type instruments.

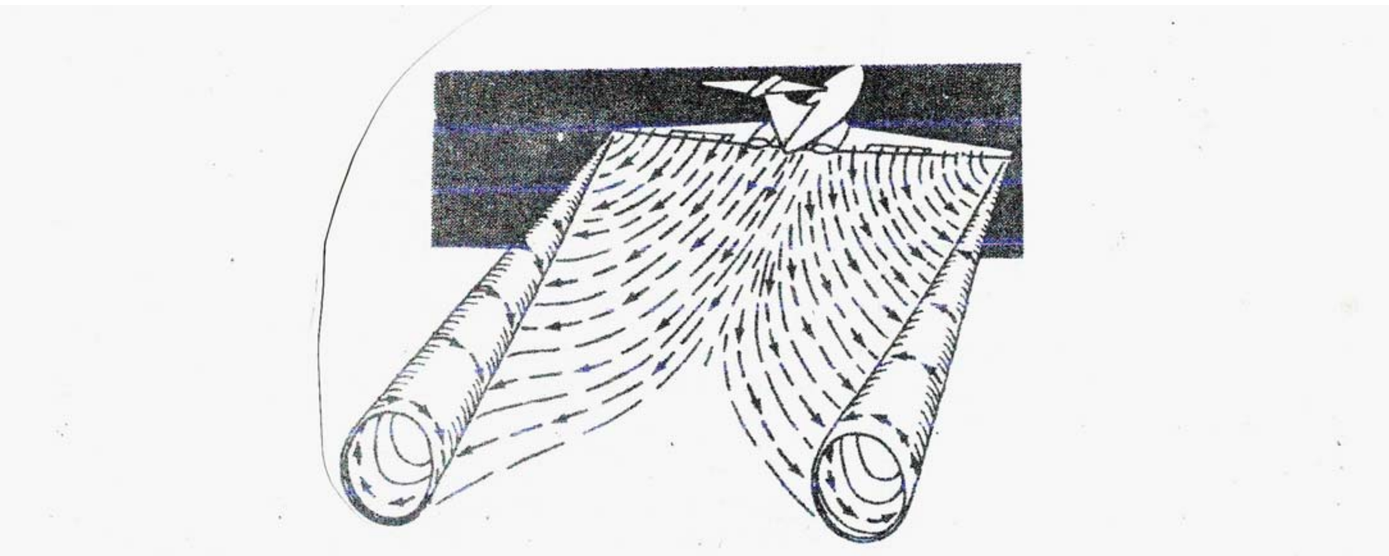

Fig 14: Wake Turbulence

The Weems plotter does have a resolution of 1°. With modern Aero Navigation systems, a small average angular error is practical. Rough air does make the task of holding a precise heading more difficult. Roll about the longitudinal axis often results from turbulent air. In 4,600 hours of Aero Navigation & flying (mostly lightplanes), the author can recall 3 occasions when the plane continued to increase roll, even after application of full aileron, until the plane reached a 45° bank. The first was adjacent to the Sacramento Mountains, a few miles South of Alamogordo, New Mexico; well known for its atmospheric turbulence; & certainly the most beautiful mountain range he's ever seen (in 30 countries). The next was over New Orleans, when in solid "soup" (fully engulfed in clouds; IFR), probably caused by "wake turbulence" from an airliner. And more recently, while IFR near Houston Hobby airport; most likely also wake turbulence. This latter experience was on one of hundreds of flights on his daily commuting flights (for 4 years) from the Southeast side, to the Northwest side of Houston; a truly great & enjoyable opportunity. He averaged 1 IFR flight per week. His most enjoyable, though least efficient commuting flight, resulted in a relaxing "approach to minimums" (see the instrument approach course in this Aero Navigation series) without breaking out of the low cloud deck, followed by executing a missed approach, a return to the departure point; & a drive to work.

See Fig 14 for an illustration of "wake turbulence". Wing tip vortices are formed by all planes when the higher pressure air under the wing escapes toward the lower pressure air atop the wings. The outward flow under the wing, & then inward flow atop the wing creates a spiraling air flow; called a wake turbulence vortex. If a smaller, lighter plane flies into the vortex from a larger, heavier plane, it will experience a tendency to roll about its longitudinal axis. The heavier & slower the large plane is, & the fewer lift enhancing devices are deployed, the more serious the roll will be. The greater the disparity between the weight of the wake turbulence generating plane & the "victim", the more serious the hazard. To the left & right of center, the wake turbulence vortex is a vertical current, so it can cause a vertical movement of a smaller plane wing.

Investigators have blamed wake turbulence for a few large plane crashes. Care & knowledge of wake turbulence reduces the risk of wake turbulence hazards. A wake turbulence vortex is not generated before lift-off, or after touchdown, so lighter planes should operate within the "safe" range. FAA Tower routinely verbalizes this warning & attempts to provide adequate spacing. Lightplane pilots, in particular, try to avoid the hazards of wake turbulence. The tangential velocity of wake turbulence can be as high as 300 fps (205 mph; Wow). The vortex descends until leveling off at less than 1,000 ft below the initial altitude.

Turbulence, regardless of the source, requires the Aero Navigator to pay closer attention to the CH so he can better follow mean heading to stay on course.

4.2.4.3.2 DR by use of the E-6B

4.2.4.3.2.1 Arithmetic Functions of the E-6B

DR requires measuring direction & distance to fly, correcting for drift that will be caused by forecast wind, magnetic variation, magnetic deviation, & arriving at the destination. If all inputs are precisely correct, & nothing changes, arrival at the destination at the ETA is assured. In fact, variation is likely, so in-flight corrections are to be expected. Speed, distance, & time are important, & somewhat obvious.

Given a distance of 180 NM & a cruise speed of 120 kts, the flight time, if there is no wind is pretty easy to determine, as follows:

Flight time = Distance / Ground Speed = 180 / 120 = 1.5 hours; or 1:30

Adding a crosswind component complicates the computation. It is inconvenient, at best, to include a crosswind without an E-6B or equivalent.

The very old ingenious E-6B is an indispensible tool for the Aero Navigator. The various functions of the E-6B include:

- Several conversions
- Several corrections
- Multiplication & division of specific parameters such as minutes & hours on the arithmetic side. .
- Wind effects based on vectors

The arithmetic side of the E-6B is little different than an Engineering calculator; but even the old E-6B has some special, vital features. Fig 15 & 16 illustrate some arithmetic capabilities, while Fig 17 & 19 - 22 give details on wind drift & its impact on the plane. Fig 17 schematically relates the E-6B to a vector solution for W/V.

A simple look at the wind vector involving only cardinal points might have a TC of South (180°) & a wind out of the East (90°). Thus a very simple trig problem. Assume 100 TAS & W/V of 20 (mph or kts, as long as units are consistent). Assume a distance of 132 miles (or NM).

Since vectors are orthogonal, the 3 vectors form a right triangle. The plane must head East of 180°, & fly a longer distance through the air than without a crosswind.   The hypotenuse is the TAS vector of unknown angle (heading), & the speed is 100.   The other 2 vectors are 180° & 90°.

$(TAS)^2 = (W)^2 + (GS)^2$

$100^2 = 20^2 + (GS)^2$

GS = 98, so he lost only 2 mph or kts; not bad.

But what should his heading be; TH?

Inverse tan of 20/100 = 11.3°

TC - 11.3 = 168.7°; or 169 realistically.

Time is per above:

132 miles to travel at 98 GS calls for 1:21; 1 hour & 21 minutes.

The above is simple enough, but not if TC were 166 & wind direction were 93°. That is why the E-6B is so very useful.

Without the DR computer (E-6B), a complex calculator,. a computer, or drafting equipment, it would be difficult to determine the direction of flight, or time to reach a destination.

A "preflight" using D.R. should be the starting point for any flight. Even if the Aero Navigator-pilot flies a particular route every week, he still needs to perform a preflight to accommodate "current" winds & weather. He may "always" fly at 10,000'. On a given day, low clouds, or severe head winds near 10,000' may force him to select 3,000'. At that altitude, he may be required to deviate around a mountain, high density traffic area, or a military restricted area. A route change would necessitate a more serious change in his preflight.

In flight, if heading can be held within 5°, & flying for 3 hours to cover 360 miles at 120 GS, the destination can be reached with an error of:

360 X sin 5 = 31.4 miles off course.

Or a "rule of thumb" is: 1° error in 60 miles results in being off course 1 mile. 360 / 60 = 6

6 x 60 miles traveled. But 5° gives 5 X 6 = 30 miles off course.

With a visibility of 15 miles, which may exceed typical visibility in the North-Eastern U.S. or the L.A. CA area, he is not likely to see his destination. Since much of the Midwest & Western U.S., the visibility is typically 30 to 100+, he should be able to see it. But will he recognize a large city, or even a small town from that far away? Or will he even fly high enough to see it that far? See Fig 26; a table of visual line of sight vs. altitude. DR alone would not be adequate for such a short trip; much less for a long flight.

It seems that it would be necessary to use some form of Aero Navigation to supplement DR. A nearby mountain, river, lake, tall smoke stack, or something to provide at least a little map reading capability seems necessary. Any of those items that might be near the intended ground track at some point would be a big help. A large river that has a sharp bend near the course line might indicate drift off course.

It is obvious that even though no flight can be conducted without DR, most cannot be successfully completed with only DR. If the visibility is reported to be 30 miles, & there is a very distinctive landmark 30 miles off your course half way to the destination, it would be prudent to look for it. If it is barely visible; looks a little hazy, that is a poor, but a useful bit of info. Hazy, with 30 mile visibility, & thought to be 30 miles off course, means he is probably not far off course.

If the wind is directly on his nose at 15 mph, he will be 45 miles short of his destination as his ETA indicates arrival. If that wind is directly off to one side he is even worse off; with arrival a little late, but 45 miles off course.

Another complication is climb speed & time. If the flight is to be made at a high altitude this can represent a significant factor in preflight as well as the flight proper. Winds will vary during the climb, so must be accounted for. Since such information is neither precise nor specific, the flight will generally deviate from the preflight. The winds aloft should be analyzed & climb speed integrated into the computation. Climb speed may vary with winds, if desired to escape a strong headwind quickly, or if it is best to climb slowly to gain a higher climb speed & cover more ground during the climb.

The E-6B was developed in the early days of aviation, & is still the favored essential D.R. tool. Without an E-6B or equivalent, D.R., & Aero Navigation in general would be impractical, if not impossible. The E-6B is a 2 sided hand held device that allows Aero Navigators to perform Aero Navigation computations.

One side of the E-6B is a rotary slide rule with aviation related calibrations, plus additional windows & features that are specific to Aerial Navigation. It makes multiplication & division easy, & deals with minutes or hours with equal ease. It even simplifies conversions, which are in effect, just multiplication & division. It permits similar computations that would require a series of very complex computations without the E-6B. Converting IAS (indicated air speed) to TAS (true air speed) for the effect of ambient atmospheric pressure & temperature on would be especially difficult without an E-6B.

A preflight first requires measuring TC (true course) & distance on a Sectional chart. It then requires consideration o aircraft performance including the anticipated climb speed, cruise TAS, & climb rate of the intended plane. Then winds aloft forecast should be obtained & analyzed with relation to the other data. This may be obvious, or it may require comparing a series of altitudes. Optimum altitude should be selected.

The E-6B wind vector face should be used to determine wind drift & more importantly the GS (ground speed). The E-6B will also display TH (true heading) for the flight. Note that the winds often vary along the route, so multiple wind vector computations may be required.

E-6B arithmetical face is used to compute time, knowing GS & distance. Finally the magnetic variation should be applied to the TC to obtain the MH (magnetic heading). Then apply deviation to the MH to, apply to obtain intended CH (compass course). Magnetic variation may also vary along the route, so may, along with wind changes, require heading changes during the flight.

Fig 15 shows the author's WWII War surplus plastic E-6B, because it is more "photogenic" than his smaller all metal version. The basic purpose of this side of the E-6B is provided by calibrations on the fixed & movable discs. The adjacent inner scale has calibrations identical to the outer fixed scale; taken as minutes, speed in kts or mph, & distance in nautical or statute miles. The second inner scale on the movable disc is calibrated in hours & minutes; & read against the outer fixed scale. Both can be taken as time units, or speed & distance units.

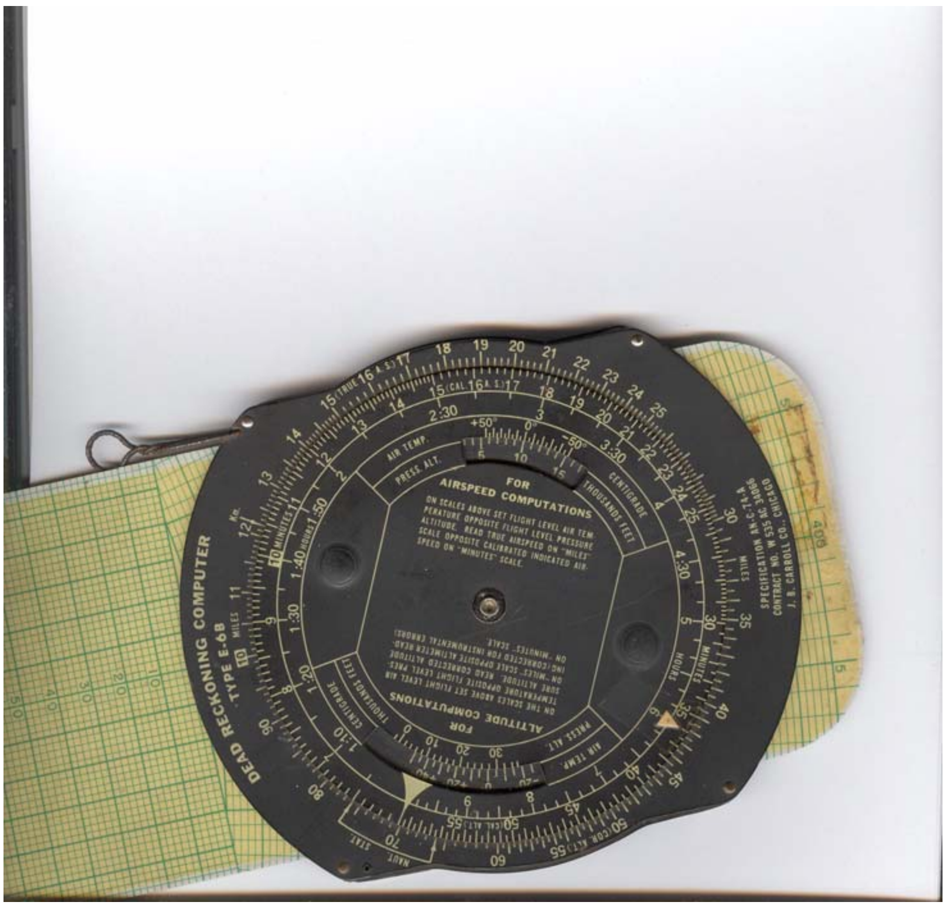

Fig 15 - Arithmetic Computation Side of E-6B

Other important features on the arithmetic face include calculations of total fuel burn during a flight, given time & GPH (gallons per hour).

The adjacent inner & outer main scales can also be used to convert knots to mph, or visa-versa.

Both altitude & temperature are accounted for by use of smaller "windows" in the movable scale. Like the old Engineering calculators, the E-6B has an index at unity, but also an index at 60 (for minutes per hour), since time is an important aspect of Aero Navigation. Like most (excepting very specialized types) rotary & linear slide rules, the "1" may represent 0.001, 0.01, 10, etc. The Aero Navigator must know the "ball park" answer to properly position the decimal point.

Readers who "predate" the hand held calculator, or were trained in slide rules for any of several reasons, will recall that the Engineering slide rule had only a 3 decimal place accuracy, & no direct decimal point information. Users must determine the correct place for the decimal point, & position it manually.

This Aero Navigation rotary slide rule is the same way, of course. An indication of 1 mile is no different than 1,000 miles until the user determines how many zeroes to use. In the case of flight time he must also determine whether the time should be in minutes or hours. Reading 21 minutes for 3:30 (3.5 hours) or vice versa would nearly have to be deliberate; just too obvious, but care is necessary. There are other cases in Aero Navigation where the pilot must know his approximate position before making a positive determination of same. The LORAN-A was a good example of this.

In Fig 15**,** the main index on the inner – rotating disc points at approximately the 35 minute clock position; just past the number 70 on the outer fixed scale. If the 70.4 represents 70.4 mph the distance traveled in 15 minutes on the inner rotating scale is 17.6 miles. Or the distance traveled in 3:30 on the inner rotating scale would be 211 miles.

Knowing that temp has less impact than one might expect because Emile Clapetron derivation of Boyles Ideal Gas Law & Charles's Law states that temperature & volume are inversely proportional, but the temperature units are Absolute Temp, so the change is minute compared with degrees F (50°F to 100°F is not 2 x, but 559.67 / 508.67 = 1.1 x on the Fahrenheit - Rankine temp scales; quite a low impact).

Avogadro's Law seems more fitting for the free atmosphere of this case. It is appropriate for comparing the same substance under two different sets of conditions, the law can be written as:

$P_1V_1/T_1 = P_2V_2/T_2$

One would then expect the E-6B to show a similar effect. Set an E-6B as shown in Fig 15.
● Note that with the above values set with 0°C opposite 10,000' altitude, read opposite 170 IAS the TAS of 199.
● Now set +50° opposite 10,000', & opposite the same IAS read TAS of 217.
● Then set 0°C opposite 5,000' altitude & read opposite 170 IAS the TAS of 181.
● Doubling temperature on the Fahrenheit scale adds 18 kts to TAS.
● Halving the altitude reduces TAS by the same 18 kts TAS.
● Conversely, double altitude; set 20,000' opposite 0°C, & find adjacent to 170 IAS the TAS of 244 kts TAS; up 45 kts.

● A word of caution. IAS actually decreases as altitude increases, so these comparisons merely represent the relationships of temp & altitude rather than presenting realistic values.

The air speed indicator must read IAS for the pilot to fly safely, as will be explained later in this course ,

The E-6B is capable of one more frequently used conversion by the Aero Navigators who prefer to use statute miles; the statute to nautical mile conversion at the lower left of Fig 15 can be used. As set, it indicates that 56.6 NM = 65.1 statute miles. Since the NWS & FSS (Nat'l Weather Service & Flight Service) report winds in knots, it is more convenient to use knots for all velocity related computations. The only place where the statute mile is officially used in aviation is, for some unexplained reason, RVR (runway visual range); visibility near the touchdown point. For visibility it seems irrelevant since the difference is only 15%.

Fig 16A illustrates the speed & distance application of the E-6B. Fig 16A shows the "time" index (60) on the outer-most scale of the moving disc pointing to 22. The 22 can be read as 22 miles, 220 mph, etc, depending on the application. Since only major divisions are numbered, the long arrows were added to Fig 16A to indicate that 26, 27, 28 & 29 have these values, even though one can determine these values by reference to the 25 & 30 calibrations. The second inner movable scale shows that after 1:19 (1 hour 19 minutes) in the air at 220 mph the plane should travel 290 miles. Likewise, looking to the left of the index, it is obvious that in 45 minutes the plane would travel 165 miles. Or just left of the index, in 9 hours it would travel 1980 miles. For preflight, in this example, the Aero Navigator would measure a distance to destination of 290 miles. Knowing his TAS will be 220 mph, he can find that it should take 1:19 without winds. He must, though, apply forecast winds, & use the Wind Vector side of the E-6B to determine GS (ground speed) & compute a new trip time.

If a flight is long enough to allow determination of GS & a drift angle, & then to turn to, & fly the new heading until these data are accurately known, the Aero Navigator can perform a reverse computation, & adjust his ETA. It would behoove him to also use the wind vector side of the E-6B to determine the actual W/V. This would be immensely valuable if his primary Aero Navigation aid were to fail enroute. It would also be of value to FSS (Flight Service Center) to allow them to correct reported winds. In the event of a severe change in W/V he might even prevent an emergency for a less attentive Aero Navigator flying in the vicinity. FSS solicits PIREPS from pilots who encounter any type of change that might affect safety of flight of others.

In Fig 16B the index is on 60 so that the 2 adjacent, identical scales are aligned at all divisions. It shows that at 60 mph the plane would travel 80 miles in 80 minutes, or 83 in 83 minutes, or 90 in 90 minutes. Yes, there was a time when 60 mph was quite a clip in an airplane; & even in the 21st century, Ultralights are limited to a max permissible full throttle level flight speed of 55 kts (63 mph).

Likewise, the disc in Fig 16A could be rotated so the index would point to the 12. This would represent 120 kts on the outer fixed scale near the left of this illustration. The second minor division to the right of the "60" index on the inner scale would then be aligned with the 4th minor division past the 12, for 124 miles. That would provide a distance traveled of 124 NM in 1:02 (1 hour & 2 minutes). Index would bear the number 2, which represents 2 minutes, & provides a distance of 4 miles.

Fig 16 A & B illustrate what should be the obvious to Engineers, but does simplify understanding of the divisions. It also more clearly indicates the difference between movable & fixed portions of the computation side.

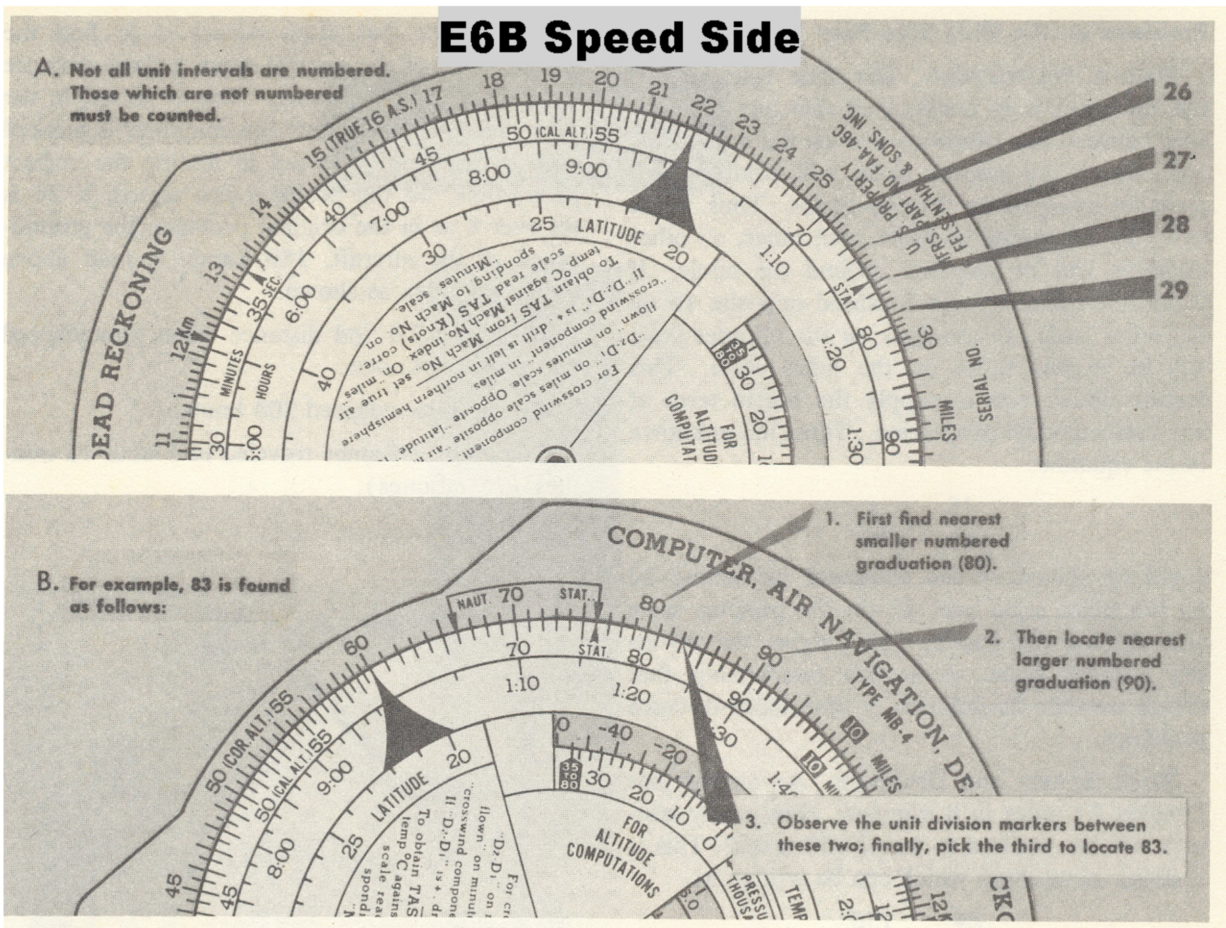

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Fig 16 - Key Points on Arithmetical Computation Side of E-6B

4.2.4.3.2.2 Wind Vector Solution using the E-6B

A modern electronic version of the E-6B performs all of the usual E-6B functions. It is similar to a typical hand held Engineering calculator. The internet offerings of an "E-6B emulator" are quick & easy for preflighting immediately before departing home for the flight. Or the Aero Navigator who has wireless internet may elect to use it in the air. A laptop or programmable hand calculator could easily be programmed to handle the complex forward & reverse wind vectors with an infinite variety of combinations of angles & speeds by use of the following equations:

Wind Correction Angle: $WCA = \sin^{-1} [\sin (C - A) (D/B)]$

Ground speed: $GS = [B^2 + D^2 - 2 (B) (D) \{\cos (C – A + WCA)\}]^{0.5}$

Where: A represents true course, B represents true airspeed, C represents wind direction, D represents wind speed. A and C are angles. B and D are speed in mph or kts).

Fig 17 illustrates an "extended" wind vector layout. The dark, heavy outlined rectangle with rounded corners overlaying the expanded illustration represents the E-6B sliding panel. This clarifies the concept of the wind vector side of the E-6B. The origin represents zero mph, so is not included on the actual slider. The 30 to 150 mph (or kts) arcs are represented by full circles, & the arcs extend to 300 mph.

The "Wind Vector side" of the E-6B provides for solution of trigonometric problems; for calculating:
● The effects of wind on cruising flight; drift & GS.
● The W/V, when the Aero Navigator establishes a fix, so is able to enter TAS, TH, TC, GS (drift angle is the difference between TC & TH.

A graphic solution similar to the wind vector shown in Fig 13 can be can performed using this wind vector side of the E-6B. The rotating disc & slider allow the Aero Navigator to determine anticipated drift off course by the inevitable cross winds, as well as the impact of winds upon speed over the earth (GS): As with the slide rule side of the E-6B, the wind vector side can be used for any variable that happens to be an unknown; thus forward or reverse. As a flight progresses the plane may drift off course. If navaids allow determination of a fix, the Aero Navigator can use the Weems plotter to measure the "revised desired TC to destination, & the actual drift angle for that 1st leg of the flight. He can then use the slide rule side of the E-6B to determine ground speed.

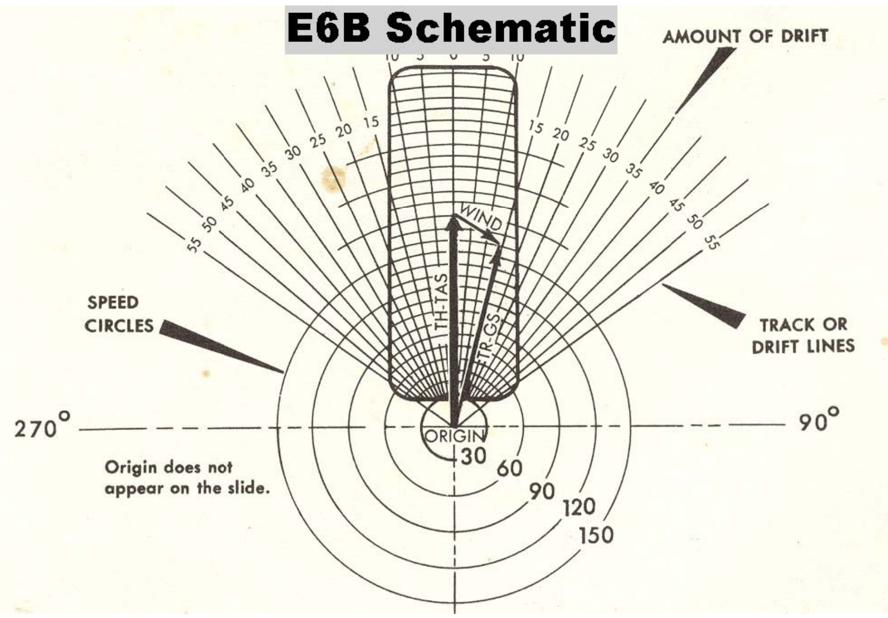


Fig 17 - E-6B Wind Vector Schematic

This information can then be entered into the wind vector side of the E-6B to determine the actual W/V. If necessary, this new wind info may be used to repeat the "preflight Wind Vector computation" to provide new Aero Navigation info including optimum compass heading, & a new ETA. The wind vector portion of the calculator consists of a rotatable ring that is calibrated in degrees. The rotating ring is integral with a large translucent disc with identifiable center mark about which the ring & disc rotate. Behind the translucent disc is a slider containing radial lines that are calibrated in drift angle, & "speed arcs" calibrated in speed units. The slider may be moved up and down underneath the disc.

Fig 18 illustrates an ACAD plot of a preflight wind vector problem. The same "plot" was performed using the wind vector side of the E-6B, after determining the details during the preflight by use of a Weems plotter, & a compass; or a pair of dividers.

The E-6B wind vector side is illustrated in Fig 19 & 20. The sequence of operations are:

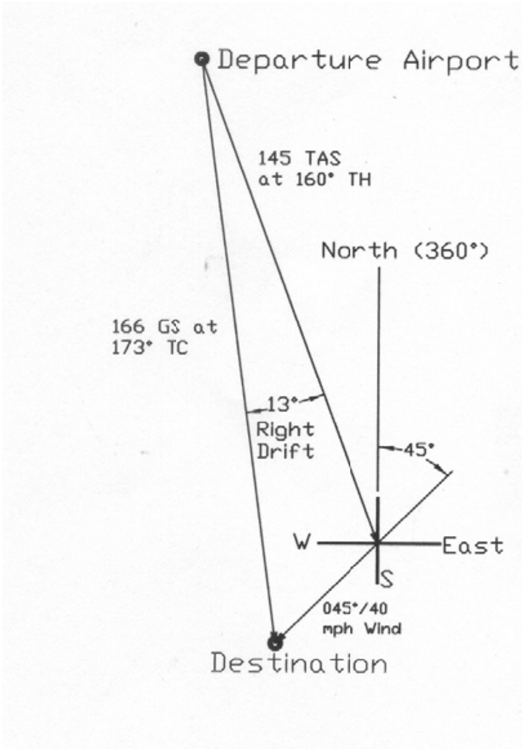
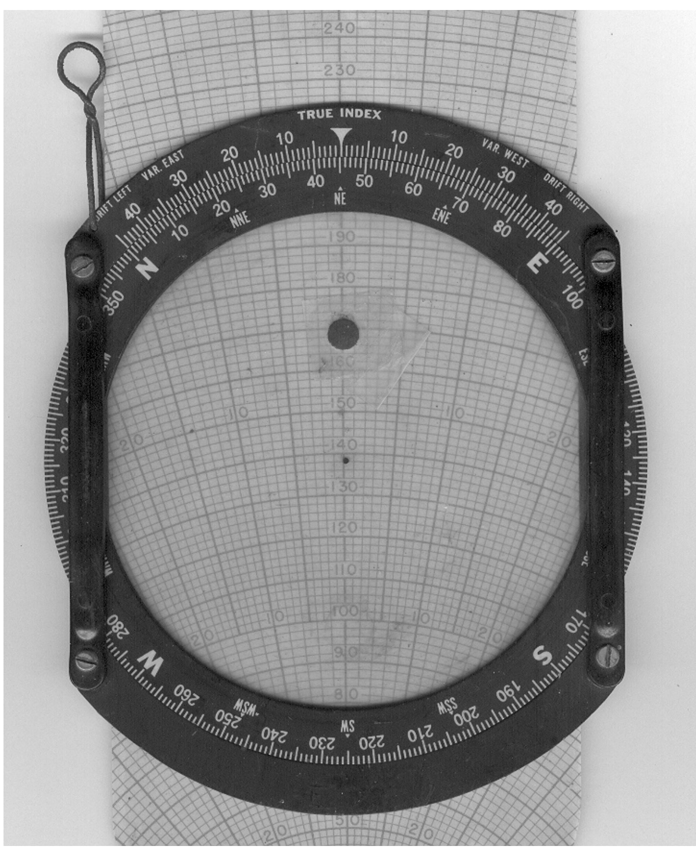


Fig 18: Wind Vector per Fig 19 E-6B analysis



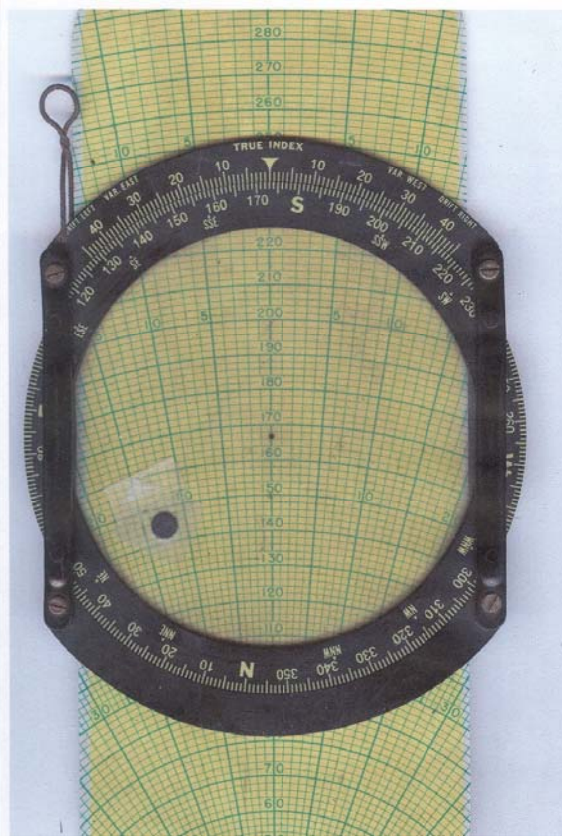


Fig 19: E-6B Wind Face

Fig 20: E-6B Wind Face

a. Rotate the wind side movable disc to read 45° (under True Index atop the fixed scale; per Fig 19).
b. Referring to the speed arcs, make a dot or “X” 40 kts “Above” the small reference dot on the translucent disc; which is located on the axis of rotation of the disc. It is obvious that the “dot” or “X” should be above, rather than under the center reference, because the wind is “From” 45°. In this illustration a large black circle was used to improve visibility. There is another popular & valid interpretation of how to use an E-6B; they simply treat variables differently.
c. Rotate the disc to align the TC (True Course) value of 173° with the true index, as indicated in Fig 20. This places the “dot” to the left & below the disc axis of rotation, indicating a moderate tailwind component.
d. Move the “slider” to position the TAS (145) speed arc under the “dot” or “X.
e. Read the drift along the lines that radiate upward from the imaginary origin; 13° in this case.
f. Read the GS under the disc centerline (center of rotation) as 166. In this case the numbers agree with the ACAD drawn wind vector, as they should. The E-6B is much easier to use than hand plotting, but not as accurate.

The electronic E-6B is even more accurate, & easier to use, but the old reliable manual E-6B never malfunctions. The internet is also excellent & more convenient than the manual E-6B for preflight information & computations at home. Most pilots & Aero Navigators do check weather & perform a preflight well in advance of a flight, but the winds aloft forecast will most likely change every few hours. Thus the wind & time portions of a preflight must be revised as departure time approaches. The Aero Navigator who has wireless internet may find the “E-6B emulator” ideal, “if” his notebook or lap top is small enough to handle in flight. A thorough test when no navcom is critical to assure that a laptop will not distort any Aero Nav system performance would be advisable. The lap top would also provide personal in flight com. It is actually illegal to use a cell phone while flying, & with 1 limited exception, aircraft type HF com may not be used for personal conversations. Virginia's International Communications Group developed (in 2008) a combination satellite phone and Wi-Fi system that provides Internet capability in lightplanes, including 3 telephone lines.

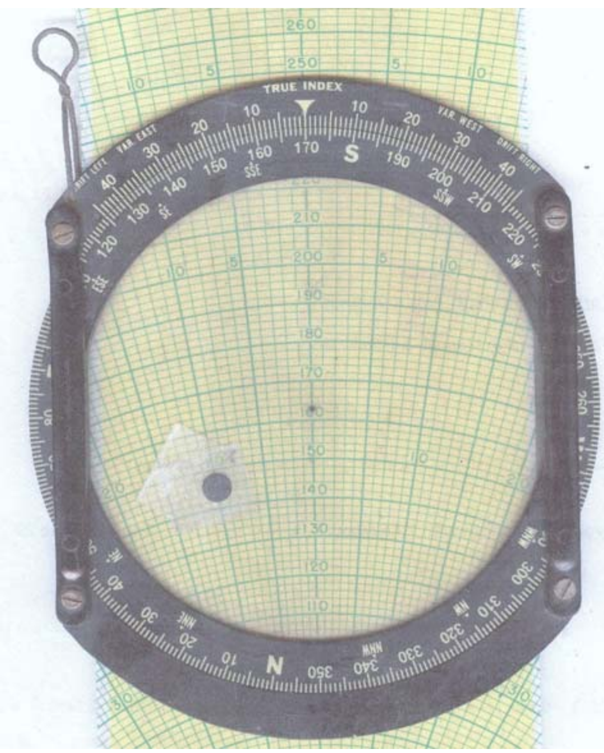


Fig 21: E-6B Wind Face

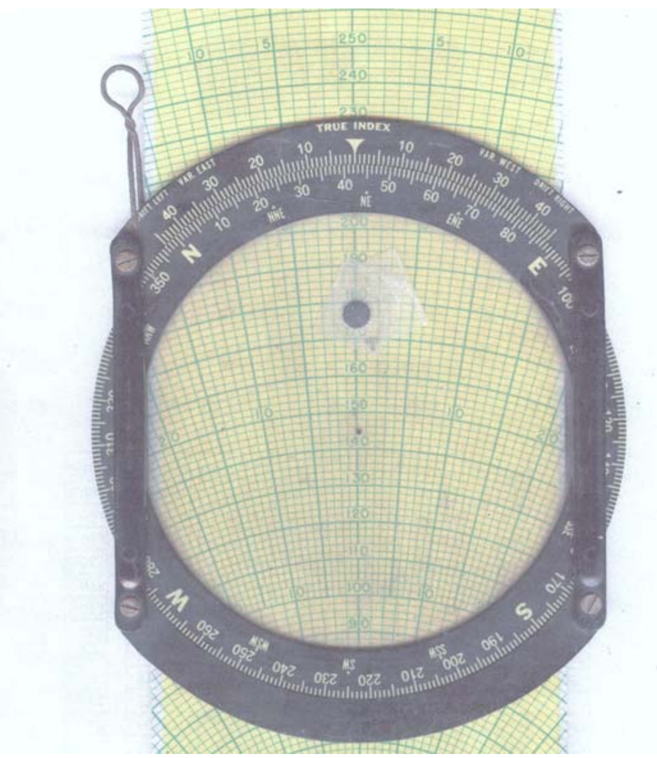


Fig 22: E-6B Wind Face

4.2.4.3.2.3 Reverse Wind Vector Problem

The intent is always to obtain accurate “fixes” during each flight; to pinpoint distance along, &/or to the side of the desired track. This info permits the Aero Navigator to determine his actual G.S. & T.C. This allows him to perform reverse computations to determine the actual W/V. If he chooses to simplify the process he can determine the desired new T.C. & estimate, from known drift, the probable desired new drift angle. This will permit him to select an estimated new T.H. & C.H. In reality, the forecast W/V, like weather in general, is often questionable.

For this flight, assume that a fix allows the Aero Navigator to compute an actual G.S. of 163 kts, & measure a T.C. of

170°; while flying the original TH & TAS of 160° & 145 kts. The below reverse computation using an E-6B shows a wind of 041/32 (41° at 32 kts). Starting with a new "off-course" fix, a new TC & distance to the destination can be measured on the Sectional chart. Depending on how far the plane is from the destination, a new drift angle, TH, & GS can be computed. To accomplish this the computational sequence should then be:

a. Compute actual drift; TC – TH = 170° – 160° = 10° drift.
b. Rotate the movable ring to place the 170° directly under the true Index per Fig 21.
c. Position the 163 kts speed arc on the slider under the center mark of the translucent disc. See Fig 21**.**
d. Look to the left (in this case) for the 10° drift radial line, & visually follow the 10° drift radial line up or down to the point of intersection with the 145 mph TAS speed arc.
d. Mark the intersection of the 10° drift radial with the 145 speed arc using a soft leaded pencil.
e. Rotate the movable ring to place the pencil mark on the vertical centerline of the slider; above the center dot of the disc per Fig 22. This indicates a wind direction of 041°.
f. Move slider up or down to any convenient speed arc.
g. Read speed difference between disc center & the pencil mark; 32 kts.
h. Thus the new wind is 041 / 32. An electronic computer analysis verifies this W/V.
i. Measure the new TC & distance to destination.
j. Perform the normal E-6B wind vector analysis using the new wind & TC from present position to destination. This is a repeat of the preflight, with updated information. The result will be a new TH & GS.
k. Turn the plane to the new TH, & proceed on course; unless as the flight proceeds, additional info (W/V or a fix) allows him to determine that additional changes are necessary.

On very short flights the above is not practical. Simply adjust TH based on known or an "intelligent guess", & proceed. On longer flights several repetitions of the above sequence are likely. Typically a 10 minute flight would be considered short. Long infers several hours; possibly 1,000 miles.

A problem not discussed above is the possibility of a large change in W/V well into the flight, instead of a minor change over a long period of time. It is apparent that such inconsistencies justify frequent fixes. Although "pure" DR has no fixes, some use of DR is important for all Aero Navigation systems.

4.2.4.3.2.4 In-Flight Course Correction by Solution of a Wind Vector by E-6B or Plotting

Fig 23 illustrates an uncompensated (unknown) major W/V change, such as is often experienced when crossing a "Frontal Boundary". Aerial Navigators must always be prepared for unexpected W/V changes. Large errors in forecast winds are commonplace; as are unpredicted enroute W/V changes. If no available Aero Navigation system is capable of providing a fix, DR is not likely to lead one to the desired destination. Even a "homemade" Driftmeter would save the day if nothing else is available. The simple driftmeter shown in Fig 52 of the second Aero Nav system in this series could be made easily with a minimum of tools. Fig 23 illustrates the impact of failure to detect & correct for a wind reversal. Assume that a frontal passage midway thru the flight results in an exact W/V reversal; from 270/38 to 090/38. If the Aero Navigator is initially unaware of the wind reversal, he will continue to fly with a correction for the 38 kt wind from the East, & be 38 miles off course as he passes the intended destination on a 1 hour flight. As shown he flew on course for the first half hour, by applying actual W/V. He continues his TH as though the W/V had not changed at midpoint of his flight. From that point on his correction is exactly the reverse of what it should be, so he in effect has twice the crosswind component that he should have. TC has full W/V correction plus actual drift. Pure DR certainly has its risks.

For the sake of this example, assume that he eventually discovers that a major wind change (not yet that it was a wind reversal) has occurred, as shown in Fig 24**.** He will determine that, 23 NM from the previous known "on-course" fix, & 12.5 NM West of the intended course. If he assumes that the wind shift occurred immediately after passing the last fix. He should then use the Weems plotter to determine the correct TC to the destination, as identified by the note "revised course to destination"; is 18°. He will then apply his best known wind vector, as shown by the arrow that points to the destination from the East. Then he should draw a line to the tail of the wind vector, as shown, & determine that his TH should be 33° (15 + 18). He should fly that TH, per the note "Revised heading to destination". Large change in wind speed is commonplace. On a very long flight, or if the plane is suddenly discovered to be quite a large distance off course, it may be prudent to quickly mark the new position on the chart, & immediately draw a new TC from the new position to the destination. Turning quickly to a new TH that he "thinks" will apply the actual drift angle. His new heading would not precisely correct for the wind, but it would represent a reasonable approximation. Unless all headings, locations, & times are precisely accounted for an estimated heading would degrade the accuracy of the final correction, but it may still save time.

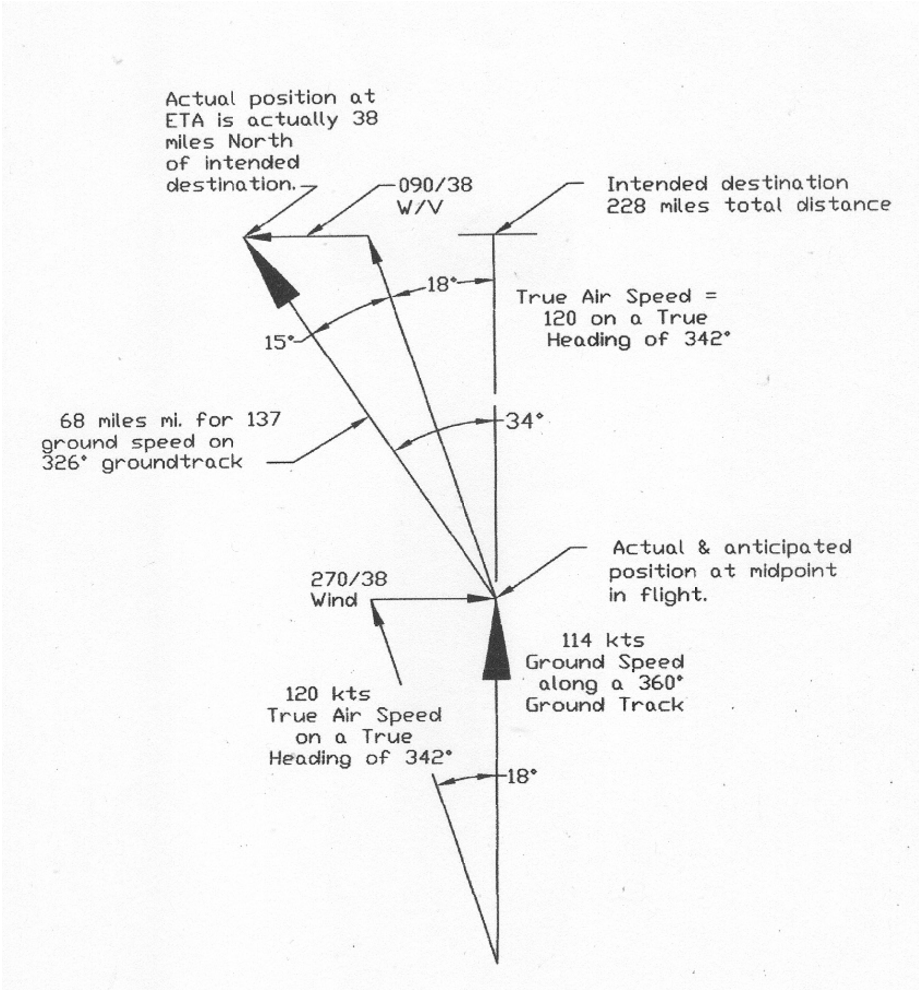


Fig 23: Wind Triangle for Dead Reckoning Nav. with undetected & thus uncompensated wind shift midway through flight; resulting in serious Aero Nav. error. W/V shifted from 270/38 to 090/38 midway throufgh flight.

FSS briefers usually ask during preflight briefings that a pilot call in PIREPs if appropriate during a flight. A PIREP is a report of anything that might be helpful for, or even constitute a flight hazard for other pilots. These reports may pertain to W/V, severe turbulence, heavy smoke, severe weather, low visibility, or any other unexpected or potentially hazardous conditions or events that they encounter. As indicated above, a severe wind reversal would certainly be of value to center, FSS, & other pilots.

The above in-flight wind vector can be helpful, but it’s nearly as difficult as if performed while driving a car; or sitting in it beside the road. There are 3 much more practical options: the old but dependable E-6B, the modern hand calculator version of the E-6B, or a programmable handheld Engineering calculator. Both “mathematic computer” & “wind vector” capabilities will be required. Less convenient, & much bulkier, is a lap top computer with Internet access. The E-6B emulator is easy with the lap top. A computer with an appropriate program is also practical.

For “preflight” planning of short flights, “winds aloft” at appropriate altitudes may not be of value, since the climb would consume much of the distance if winds are better at a high altitude. Most XC flights justify a review of “winds aloft”; W/V. For airports near sea level, winds aloft are given at 3,000’, 6.000’, 9,000, 12,000’, 18,000’ are adequate for most lightplanes. Altitudes are MSL. Wind direction is relative to True North; not magnetic, so variation correction must be applied. Surface winds are also reported, but not convenient to winds aloft. Surface winds are given in magnetic directions to facilitate TO & landing. Winds aloft are not given at any altitude that is within 1,500’ of the ground level at the reporting station or airport.

For jets & high performance lightplanes the next few winds are for 24,000, 30,000’, 34,000, & 39,000, 45,000, & 53,000’. They are reported for pressure altitude, since planes at & above 24,000' fly with altimeter set to 29.92; standard pressure.

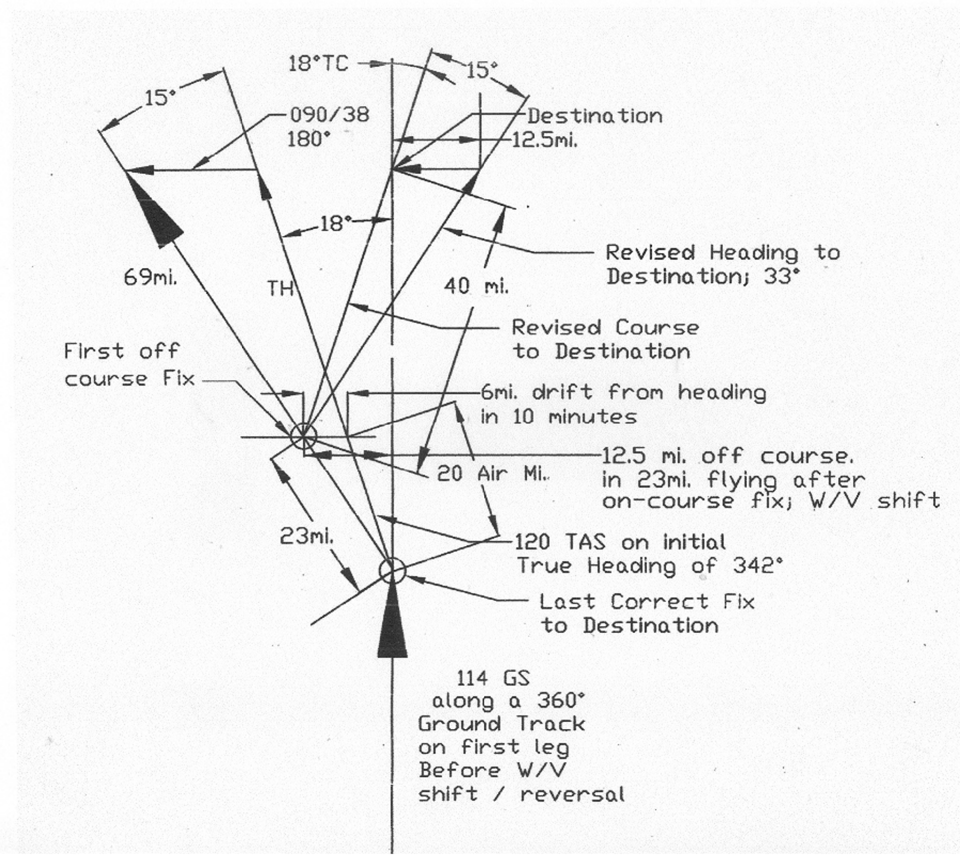


Fig 24: In Flight Correction of W/V change induced off-course deviation based on second fix vs. midcourse on-course fix. Course & assumption by Aero Navigator are that wind shift occurred immediately after first fix.

If the most favorable W/V is obvious, such as a direct tailwind at all practical altitudes, a casual analysis of the forecast may be adequate. Even then, time to climb must be considered if tailwind improves with altitude. If climb will take half the distance it is obviously not worth the fuel burn & lower ground speed during the climb. The climb analysis is part of the responsibility of the Aero Navigator. If best choice is not obvious, an E-6B Wind Vector analysis should be performed. Again, a visual analysis can eliminate some obvious poor choices, although wind influence is not intuitively apparent.

Fig. 25: Influence of wind & TAS upon GS						
All winds given as 20 kt; direction as angle off nose.						
Wind, Degrees	0	30	90	0	30	90
TAS:	100	100	100	150	150	150
GS:	80	82	98	130	132	149

Fig 25: Influence of Wind & TAS Upon GS

The table shown in Fig 25 gives an indication of the impact of a few crosswind components vs. TAS values. The data could have been generated by any of the methods that were discussed above, including the E-6B: Note that even a 90° crosswind does not have a major influence on GS. Also that higher TAS planes are, as expected, not slowed down as much as slower planes. Obviously a tailwind component is more desirable.

On a 100 mile flight, the W/V at 15,000' is irrelevant for most lightplane. A high velocity direct headwind demands consideration of other altitudes. This table makes it clear that an E-6B Wind Vector analysis is generally desired.

Nearly all flights do involve some winds, which must be accounted for. Both winds & true course are referenced to (measured from) true North. True North is indicated on a Sectional chart (see fig 8) as a thin black N-S longitude (great circle) line; adjacent Longitude great circles on a Sectional are located 30 arc minutes apart.

4.2.5 Limitations of DR

Pure DR is usually impractical for long flights because of both the inability to hold a heading with acceptable accuracy, & the inaccuracy of forecast winds.

Other Aero Nav systems in this series show how to measurably improve the accuracy of DR when there is no Aero Nav method capable of providing fixes.

One of the most "miraculous" & famous flights in history involved all likely DR inaccuracies; "to the extreme". One of the course writer's heroes; Charles Lindbergh, officially flew 3500 miles (actually considerably further since his flight was certainly not a straight line; nor did he follow a great circle). The flight took 33 hours & 30 minutes, while burning all but 85 of the 451 gal. of gas that he started with. He averaged 104.5 mph, 10.9 gph, & 9.56 mpg.

He had overcome sleet, fog, overwhelming fatigue, & sleepiness. Had he averaged only a 2° heading error for all flying when he was alert, & another 2° wind correction error he'd still have missed his landfall by 233 miles. But he was groggy with fatigue, so rarely actually alert. Long term, long distance wind forecasting in those early days of aviation were unlikely to be better than 20°. He once awoke 90° off his heading, & had no idea whatever how long he'd slept, or flown off course. Each minute that he flew at 90° off his planned heading he moved 2 miles further off course. Considering the unknown of winds plus inability to hold a precise heading in his fatigued condition, he could have easily averaged 10° off course; 600 miles off intended landfall. As for the accuracy of holding a compass heading in rough air, while suffering from severe fatigue, the reader might imagine how accurately he could hold a compass heading while driving at a high speed over rough terrain in a wilderness area (causing the compass to swing wildly); with no distant reference (aiming) point to facilitate holding a heading. Or the reader might have tried to hold a compass heading in a boat, bouncing along at high speed, on rough open water, with a wildly rotating compass. For virtually the entire flight Lindy had no ground reference to give him any idea how far off course he might be during that historical flight. Previous attempts to do what Lindy was able to accomplish had claimed the lives of several accomplished pilots before him. Of course, few, if any pilots in history ever approached Lindy's skill & knowledge level.

Lindy resigned his commission as a Colonel in the Army Air Reserves on April 29, 1941 out of frustration over FDR. That was before WWII, but after his official visit to Germany, at President Roosevelt's request, to determine the status of Hitler's combat aircraft. Roosevelt did not care for Lindy's accurate analysis, so refused to authorize his return to active duty. Lindy did serve in the Pacific theater during World War II, as a technical advisor, over the objections of Roosevelt, who allowed petty political differences to place the very lives of American military men & the future of the country at risk.

Lindy was a tremendous asset to aircraft manufacturers during the war, but FDR demanded that all who had used his consulting services cease immediately. Henry Ford disregarded FDR & apparently saved many American lives by doing so.

General Mc Arthur, who was a close friend & admirer of Lindys, forced the issue, & brought him to the South Pacific theatre. As a result Lindy was able to save hundreds of American pilot's lives by actually teaching many fighter pilots, & indirectly all military pilots, how to increase the range of their planes by an unbelievable 100%; thus ending a series of costly, often tragic ditchings at sea. He was able to save fighter & bomber pilot's lives by teaching 2 important issues. The "conventional wisdom" among pilots at that time included 2 erroneous "rules of operation". Both of these misconceptions are still taught by a minority of pilots.

One of Lindy's major lessons involved the "over square" rule. Lindy either developed, or agreed with the concept of countering the "conventional wisdom" of avoiding operation of engines "over square". Over Square is defined as operating at manifold pressure greater than "hundreds of rpm". An example of "over square" is to fly at 28" MP (manifold pressure; measured in inches of mercury) & 2200 rpm. The" Over Square" rule would limit MP to 22 "Hg at 2200 rpm. At high power settings, "over square" would cause detonation, & very likely engine failure. Conversely, properly understood, & cruising at moderate power settings, over square is not only safe, but measurably reduces fuel consumption. In combat operations, that could save the lives of numerous flight crews. In fact, Lindy actually did save many lives, as a result. Fuel consumption increases much more rapidly with increasing rpm than it does with increasing manifold pressure. To pick some arbitrary numbers, assume that 28" Hg & 2200 rpm would produce 60% power, & that the reverse would produce the same power; 22" Hg at 2800 rpm (actually most aircraft engines turn slower than that, & radial engines turn much slower). In this case the first set of parameters might result in a fuel consumption of 20 gph. In that case, the second set of numbers might result in a fuel consumption of 30 gph. The higher the rpm the greater the fuel burn in gallons per horsepower.

The other method that Lindy advocated was to “over lean”. To do so he operated at low enough power to permit leaning much more aggressively than “conventional wisdom” suggested. That was before the days of EGT (exhaust gas temperature) instruments, but in more recent times Al Hundere, the undisputed top expert on aircraft engine performance, & founder of Alcor, agrees with Lindy on these 2 fuel saving measures. Alcor manufactured the first, & remained the leader as others copied his instrument for measuring EGT. Manufacturers claimed that an EGT instrument would last 5 years. Al Hundere was pleased to hear the author announce, before a crowd of hundreds at the great EAA Oshkosh Fly-in, that his Alcor EGT lasted over 30 years. An engine should normally be “leaned to peak” EGT, once established in level flight cruise, at altitude, & then “richened” by 50°. If cruising below 65% power it is acceptable to lean 50° on the “lean” side of peak. The fuel consumption is measurably reduced without loss of power, & without risk of engine damage.

Lindy spoke with an entire squadron of P-38 pilots, advising of the merits of these 2 methods. They were skeptical, so he offered to fly with them to prove his point. He flew combat missions & returned with over half of his fuel. That convinced them, & the result was an unbelievable doubling of range. The combat range had been 6 hours & 900 miles to target at 300 mph. P-38 crews began flying 12 to 14 hours, & 1800 miles to target; 3600 miles round trip. This resulted in an enormous increase in the destruction of Jap combat operations. Some WWII P-38 pilots told the above stories in a History channel video series, & also claimed that Lindy made a greater contribution to the winning of the Pacific war than any other individual. Most of this was also documented in assorted books & articles.

Lindy was also able to shoot down at least 1 Jap plane while flying a series of missions in the famous P-38 Lightning. He reported that he could see the cooling fins on the engine before they both pulled away from the head-on battle.

Another means of increasing the range of an aircraft is to fly it “on the step"; like speed boats. Many pilots dispute “the step”. Many prove the concept daily. Some marginally powered planes actually “drop off the step” in turbulent air, but so do some jets. The twin-jet B-66 Jet actually flew an extra hour on the step than off of the step; 4:30 vs. 3:30. Only 1 pilot in one USAF Tactical Squadron in Europe routinely flew on the step at the same speed as others flew, but he reduced power to permit flying roughly 33% longer (time in the air) on the same fuel. Another example was the “hot” little 85 hp Culver V. It uses a 2 position prop (high & low pitch). Cruising a Culver V in New Mexico’s mountain & desert turbulence, the author “down-shifted” repeatedly on turbulent days, because speed dropped quickly from 130 mph to 100 or 105. as the plane “fell off the step”; too close to flap up stall speed for this hot little plane. It was nearly essential to lower the nose to assist the prop down-shift in increasing the engine rpm to develop sufficient power to “keep it in the air”, & build speed back to cruise speed. The 3 Cessnas in which the author accumulated over 3,000 hours all gained nearly 10% in cruise by flying on the step.

Each time FDR found that Lindy was in the war zone he demanded that he return.

4.2.6 Airplot

Airplot provides a simple & effective way to navigate in cases where frequent multiple heading alters are required: Deviations from the intended course were mentioned above. Thunderstorms often force erratic flight paths. In such cases multiple seemingly random heading changes may be necessary. Neither DR nor map reading are easily performed to "keep up with a plane" under such conditions. In such a difficult situation it is faster and easier to solve navigation problems by the use of airplot. Airplot is the graphic solution of the wind triangle on a chart or E6B computer for the purpose of finding a DR position or a wind. Airplot is not treated here to be a different method of navigation, but merely a difference in the application of the vectors of the DR wind triangle. It may well be called a stand-alone Aero Nav system.

Airplot becomes useful when the heading of the aircraft changes radically & frequently. It is then easier to follow the movement of the aircraft through the air mass using TH & TAS rather than computing a DR position each time the heading changes. Obviously, airplot must be performed quickly and accurately so that the final airplot DR position may be changed to a true position by adding a single wind vector for the length of time the airplot was active. The reason airplot is important is to allow the Aero Navigator to quickly determine the correct heading to the destination when navigation can be resumed. The basic reason that airplot is faster than ground plot is that wind effect is not considered until all heading changes have been completed. It is much faster to apply a wind vector 1 time than several times. At that time the net wind effect for the period of airplot is very quickly applied to the final air position to determine a ground position. To be accurate, airplot should be started at a known position; best guess if only a DR approximation. After the erratic deviations

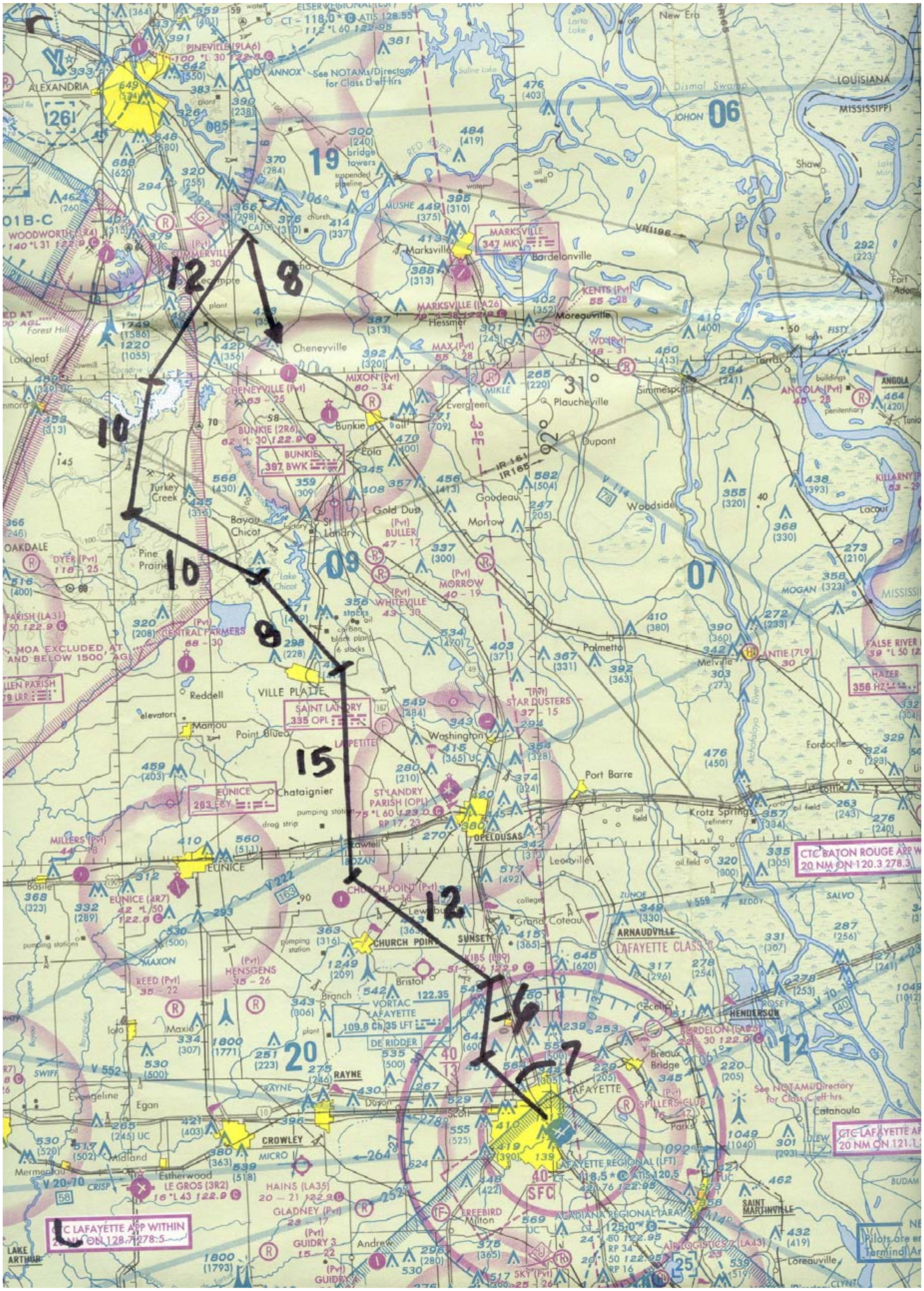


Fig 26: Airplot

cease, 2 methods are commonly used to establish aircraft position.   The first method was stated above.

The second method is to simply use the last air position as a starting point. This method is usually satisfactory only if the time spent in airplot is short and the wind speed is light. In the case of high winds, the air position might be significantly in error from the actual ground position, so is not acceptable.

It is essential to remember that the wind always blows from the air position to the ground position.

A hypothetical Airplot example is illustrated Fig 26. It represents a labor saving DR tracking when dodging scattered thunderstorms on a flight from La Fayette Regional airport in Louisiana to St Louis, MO. The plots represent MH & time for each of 8 Airplot legs. Although the legs are labeled with time in minutes on each heading, they were plotted in NM based on those times for this example. The final plot with the arrow head represents the wind velocity as applied for the 80 minutes of Airplot. Thus the length of the wind vector is 80/60 = 1.333 x the wind speed in kts. It was labeled 8, as in 8 minutes. The wind speeds corresponded to the times; in terms of TAS were for the times listed. The 7, 6, 12, 15, 8, 10, 10, & 12 minute legs represented "air distances" only; of 7, 5, 11, 13, 7.5, 9, 9, & 11 NM. TAS was only 55 kts or 63 mph. Sounds like an ultralight, but that is OK. A look out of the window should show that he had just passed Cherryville. The wind speed line was 7 NM long, representing a wind speed of 7/1.333 = 5 NM for 80 minutes. The Aero Navigator only had to concentrate on the MH values, & the time flown adjusted to NM at each vector. A little labor intensive even as airplot, but much easier than to apply wind vector to each. So as the storms all appeared to be behind him, he added the wind vector (7 NM) at the end of the vector identified with a 12 (12 NM) & establishes an airplot position.

4.2.7 Pure DR

Pure DR assumes no fixes or wind information during the flight; often with no electronics or terrain features to guide him, or allow updates of W/V, or provide an occasional “fix”. A “fix” is a positive location on the face of the earth that can be positively identified by some means. Using map reading, the next system in this series, a fix may be any identifiable feature on the earth. It could be a small point in a city, a highway intersection, or any of many such known points. Any other Aero Navigation system could also provide a fix, or even continuous ground track info. Without intermediate fixes, arrival at the destination will be questionable. The reader might ask: “Why would anyone fly with no avionics, or other electronics?” The reason is that most modern Aero Navigation systems are based on electronics, & some planes simply do not have electrical systems; some may lack even small hand held Avionics devices.

Examples of planes that are not necessarily equipped with avionics, including communication equipment: gliders, aerobatic planes, antiques, record breaking planes, sport planes & ultralights. All could add avionics if justified.

It is obvious that since electronic system failure is a possibility, a prudent Aero Navigator should always have options available. The best precaution against the risk of a catastrophic end to such an unlikely event is to frequently, use the Aero Navigation systems that are nearly always available, during XCs (cross country flight). If he does lose his Aero Navigation capability, he will always know his position, W/V, drift angle, & GS. Thus if a failure occurs, DR for the remainder of any flight is much more likely to result in safe & timely arrival at the destination. If he is precisely on course, but has no idea of drift or GS, a loss of the Aero Navigation System that he is using may result in serious problems. He might even become lost & be unable to reach his destination. Redundancy of Aero Navigation systems & proficiency in operation of all available Aero Navigation systems is essential. Pure dead reckoning is rarely sufficient for reaching the destination, so the Aero Navigator should be alert for info on both wind & position as the flight progresses. Wind can be determined in advance by calling FSS. It can also be estimated quantitatively by looking for smoke, or to a lesser extent, things like blowing dust, trees or water. A simple viable option is a home-made Driftmeter; with which drift angle can facilitate W/V computation. See the Aero Nav systems on driftmeters for potentially valuable info.

Dead Reckoning has always been used in conjunction with any available Aero Navigation system, if available. In the early days of aviation, pilots used primitive road maps to track the route as they flew. Before they took off, they used DR to conduct a preflight. Back then they had little information on winds in advance, & no means of measuring or otherwise obtaining W/V in flight. As other Aero Navigation systems were developed & perfected, the best system available to each Aero Navigator was used, if affordable.

The most basic Aero Navigation Tools that are essential for all DR flights include the Weems Plotter, E-6B Computer, & magnetic compass. Each plane is required to have certain basic instruments, including the magnetic compass.

Most of the Aero Navigation Systems described in this course provide continuous, or conveniently frequent fixes. Even the OMNI, or the very old (now obsolete) A-N Radio Range did provide continuous monitoring of course tracking. Some instantly alert the Aero Navigator of subtle or sudden changes in drift or GS. A prudent Aero Navigator will compute W/V frequently, & compare with FSS enroute reports.

4.3 Aero Navigation System No. 3: Map Reading.

4.3.1 Background:

Scientists still have no idea how birds, fish, animals, & even butterflies migrate. Man has difficulty traveling without some form of nav-aid as guides; airways, roads or maps. Early mankind may have sketched lines in dirt for the directions to a nearby point of interest. An unplanned hike in a wooded area on a cloudy day, without a compass, can prove just how easily one can become disoriented. Introduction of boats & long distance travel by foot or horse drawn coaches on paths that became roads demanded maps. Early world maps were far from precise, but as stated under Lambert maps, none are perfect.

In the earliest days of Aero Navigation there were no navaids at all, nor Aerial Navigation systems; or even concepts. Pilots initially improvised by using primitive road maps. These maps lacked the extreme detail & accuracy of modern Sectionals, so made the task of map reading more difficult & much less precise than now. City names on water towers proved invaluable. Flying low enough to read signs on buildings may have been helpful, & there were no FARs to discourage that.

Pilotage is an old, seldom used term that refers to Aero Navigation by reference to ground features; thus pilotage is map reading.

4.3.2 Theory: The more accurate & the more detailed the map the more accurately & easily it can be used. Land feature details may be compared with a chart to easily identify fixes nearly continuously.

4.3.3 Accuracy & Efficiency:

Sectional charts are not only very precise copies of land features, but large enough that 1/8" represents 1 Statute mile. Thus it is easy to establish a fix well within 1/8 mile if flying directly over a positive point. If to the side, the error might be up to a few miles. Map reading is thus a reasonably accurate Aero Nav system. As long as the Aero Navigator monitors the land features on the Sectional vs. those on the ground there is no limit to the number of miles that may be flown without drifting off course. Wind drift is automatically corrected by simply staying on course. The major accuracy concern is simply the risk of losing track of the current position; getting lost.

Map reading is efficient in that maps permit flight in any direction desired, including flying directly from departure airport to destination airport free of any deviations; thus both distance & time of flight are as short as possible.

4.3.4 Application

The most important thing in map reading is the orientation of the chart flight path with the longitudinal axis of the plane. A map turned right side up relative to the Aero Navigator is certain to disorient a person. Thus features to the left of the plane should be on the left of the course line on the chart as viewed by the Aero Navigator. Features will then be unambiguously identified. Each intricate curve, or orientation of geometric or other shapes must be easily identifiable. Even the obvious shape is easily misinterpreted or even confusing if rotated 30°, 60°, or 180°.

As aviation matured, so did charts. The Sectional charts shown in Fig 5, 9, & 12 resulted from slow evolution to include:
● All available Navigation aids as they were developed, including airways
●The least conspicuous terrain details & features
● Highways, railroads, airport symbols, airways, etc.
● Feature accuracy & detail were the best possible for the scale.

Fig 5 gives an enlarged look at a portion of the Houston Sectional, including the VOR compass rose, & a few important symbols such as the 1038 ft high tower near the bottom center. The 1038 is height above MSL. The 1005 in a parend is the height AGL (above ground level). Numerous small airports are shown. The white line in a dark airport circle indicates direction of each hard surface runway.

The Clover (identifier is LVJ) is slightly below Hobby. It has several more runways than Hobby, but only 1 is shown because the remainder are sod. The author was a member of a flying club at Clover that included an Aeronca Champ, Cessna 140, Cessna 172 (New), & a Mooney Mite. This wonderful, cute little miniature Mooney predated hydraulic brakes that did not hold well, so he had to stop in a shallow ditch to perform a magneto check at 1500 rpm. That was really not a concern. He had been taught that airplane brakes were for mistakes, so he seldom used brakes on any plane throughout his 4,600 hours in many years of flying. He thoroughly enjoyed flying this sleek single place trigear low wing plane. About 15 years later his oldest 2 sons flew gliders out of Clover. Clover was renamed after this chart was published.

Below Clover is Polly (ranch) with PVT to indicate that it is a private airstrip. That sometimes means that visitors are not welcome. In the case of Polly Ranch, it is a housing development with homes, garages & hangars adjacent to the runways. The 24 - 27 indicates 24 ft elevation, no lights on runway (would be indicated by an upper case "L"), & a 2700 ft long runway (longest if more than 1 runway).

Map reading relies on accurately defined rivers, railroads, town & city shape, highway curves & intersections, bridges, & virtually every shape or object that could be identified from the air. The Sectional is not used at 30,000' by airline or fighter pilots, but it actually could be. Fig 9 illustrates a legend enlarged to 2 pages from the Albuquerque Sectional. The numerous symbols on the Sectional are logical & precisely located & depicted. They are easily located & identified. Distance to side can be estimated & passage can be timed to obtain GS. Total flight distance can be compared with flight time to compute a revised GS, & ETA.

Although Sectionals are revised twice per year, the intent is to minimize actual changes. The FAA does require a current Sectional to be carried for all flights within the U.S. It is certainly possible that a noted change would prevent fuel starvation, failure to reach destination, etc. NDBs do change frequencies or may be shut down. VOR frequencies occasionally change, so an OMNI may not always be selected by use of an obsolete chart. VOR Aero Navigation would be useless to the Aero Navigator for at least one hundred miles if he has an incorrect frequency while following an airway. To an Aero Navigator who is proficient at map reading the loss of any modern nav aid would simply be an inconvenience.

A proper preflight study and markup of the chart is important, regardless of how sophisticated the avionics are. It should include a straight line (an approximation of a Great circle) unless deviations are necessary, such as around a Restricted area. With occasional mile marks; 10, 50, or 100 miles would suffice. A little time during the preflight may be beneficial to better understand the most important landmarks. It may reduce in-flight effort & result in a more efficient flight. A careful study of the land features within at least 10 miles of the course is recommended, with less diligent look at the adjacent 50 miles just in case of weather detours or other unanticipated changes. Marking of mileage from departure point &/or destination at a variety of check points along the route would reduce the work load & risk of becoming lost in flight. A nice convenience is marking "to" & "from" distances to provide quick distance from both departure & destination airports information during the flight.

As a flight progresses it is very important that the Aero Navigator be very alert for the GS (ground speed) changes by computing it frequently. He should note the actual time of arrival at each fix vs. the predicted time. Deviation & GS changes should be documented. If the GS changes he should determine the actual GS & the ETA to the up-coming fixes. If not, the accumulation of errors may present problems such as disorientation, fuel shortage or simply failure to maintain a correct ETA. He should not only look for a check point or fix, but verify that features around it agree. It is rare, but one feature may look like another a few miles away. It is preferable to compute W/V changes so that he will be able to determine the TH required to reach an off-course airport in the event of an unplanned stop.

The Sectional is very detailed, but may not show all land features, so it is best to look at the ground first & then the chart. Some buildings may be new, & most buildings are not shown on a Sectional; except in sparsely populated areas. Small highways are not generally shown in major metropolitan areas, but will be shown in sparsely populated areas. Race tracks are easily identified from the air, & are usually shown on charts and.

The ability to judge distances will improve the map reading capability. Comparative methods are useful. Note that any measurable distance on chart (Weems plotter) can be compared with distance off course of a check point or along course on ground. An example is easily measured ground distance, such as the length of a road between 2 curves. Altitude vs. angle out from the vertical to an object is a good technique if mastered. Vertical distances are more difficult. It is difficult to judge height of a power pole. Look at an airplane wing standing on the root end, leaning against a hangar wall. It actually looks longer than the entire wing span when mounted on a plane. It is easy to simply multiply the tangent of the angle between the vertical & the line of sight by the absolute altitude. Lightplanes are rarely equipped with a Radar altimeter with which to obtain absolute altitude, so he must estimate that by use of elevations shown on the Sectional & his altimeter reading. Obviously if he is looking down at 30° from the vertical the horizontal distance to a landmark becomes 0.577 or more practically 0.6 times the absolute altitude. At 45° the horizontal distance will equal the altitude. Looking outward further at 60° it is 1.7 times the absolute altitude. Distance can obviously be in front or to side. Aerobatic pilots add wire &/or painted stripes to aid in judging angles for precision aerobatics. A devoted map reader might consider angular reference lines to aid in judging the angle from the vertical as well as off of the longitudinal axis of the plane.

An obvious valuable tactic is to find an obvious road or river crossing the track & another a few miles ahead. Measure on chart & use distance ahead to improve distance judgment as you cross the first reference. Note time when crossing both. Use time vs. distance to compute an accurate GS.

Until confidence is gained in map reading proficiency, the ground track should be continuously monitored & adjusted to stay on course & afford continuously certain position.

Fig 12 shows a small portion of a Sectional chart. It gives an insight into the map reading process. The airports shown include Whiskey Creek at Silver City, NM near top center, Deming to far right near the bottom, & Lordsburg near the lower left. The word Albuquerque printed below the Silver City VORTAC radio frequency box indicates that communication is with Albuquerque Center. Frequency is printed at top left; 122.1R; the R indicates a "receive" frequency. Generally com is simpler; send & receive on same frequency. If flying along V94, about 21 NM West of the Deming airport the small road extending North from the village of Gage at Interstate I-10 splits into 2 roads that head roughly N & NNW. The shapes of the curves on the Sectional chart precisely duplicate the shapes on the ground. It would thus be possible to determine position from these curves. Another way would be to estimate distance between the 2 roads along the flight path, & measure that value on the Sectional. The dashed line indicating a pipeline right-of-way would also indicate, if detectable, precise location as it crosses either road. The tank & buildings near V94 are also excellent identifiers just East of the roads.

As V94 crosses I-10 between Lordsburg & the 45° turn in I-10 there should be a readily visible "station" . Under the V94 Victor airway number is a small box encloses the distance between the nearest 2 VORs; 84 nautical miles. Near that the large 7.1 & 7.4 indicate, for safety, the highest point within the parallel-meridian box that encloses them. The highest point may be simple flat terrain, a mountain peak, or a tower. The 7.1 is in the area bounded by 108° & 108°-30' meridian & between the 109° & 109°-30' parallel of latitude. The 7.4 is in the area bounded by 108°-30' & 109° meridian & between the 109° & 109°-30' parallel of latitude. Near these numbers is the Lordsburg airport with official identifier of LSB. The 4278 indicate field elevation, a blank where it may have had an L for lighted runway, & the number 50 to advise that the longest runway length is 5,000' . The 122.8 & circled "C" indicate that the common airport advisory frequency is 122.8; the most frequently used UNICOM frequency.

A more critical map reading effort would be near the mountains around Silver City, because an error might possibly lead one into a blind canyon that the plane cannot out-climb. Prudent mountain pilots never allow such a situation to develop.

It is always best to fly a precisely straight line that the Aero Navigator has drawn on the chart during the preflight, but some would prefer a shortcut; an easier way. Some jokingly say they fly IFR; meaning "I follow railroads" (or highways). In flying from Deming to Whiskey Creek it may actually be better to follow either the highway or one of the 2 power line right-of-ways, as indicated by the small tower symbols. The highway or even the power line would also provide possible emergency landing areas, as long as cars or towers could be dodged. A similar situation would be the railroad just to the West of the power line; a more hostile landing site.

The entire Albuquerque Sectional has large areas with fewer landmarks than usual. Nevertheless, it is possible to navigate by map reading dry lakes and creek beds, arroyos, pipelines, and similar nearly inconspicuous things quite safely & easily.

A marked up TC line can reduce in-flight panic level if all else fails for some unanticipated reason. It is also prudent to mark incremental distances; especially valuable if the primary modern Aero Navigation system fails enroute. If LORAN, DCE (distance computing equipment), or GPS is included on the “aircraft equipment list”, additional preflight effort in the form of programming may be necessary for a new route. The author has flown across & all over the U.S. literally dozens of times, deep into Mexico, into Canada, & to the Bahamas in the family Cessna. It seems that trips back East (even to Florida) were often mostly IFR. Nearly all flights were repeated at least a few times, to visit family, or especially to Arizona, New Mexico, & Colorado for buying American Indian Jewelry for his wife’s business; & to visit their favorite vacation spots. Most of these flights were programmed into DCE, GPS &/or Loran only once, & used repeatedly. Even programs for infrequent trips to the East & West coasts were saved, & used on several future trips. Outdated charts were saved to facilitate marking up current charts. If Northerly headings demanded inverting Sectionals, a second copy eased the effort. Sectional charts must be replaced every 6 months, while IFR “enroute” charts & “approach plates” expire in 56 days. The author also found that an Excel spread sheet was very useful in monitoring waypoints along each route. They facilitate determination of multiple distances between various waypoints for quick decisions in the event of severe wind changes or emergencies.

As stated previously, it is essential to use DR with all basic Aero Navigation systems, including map reading. It is also necessary to use the DR computer (E-6B) to perform speed-time computations as well as the wind triangle. Standing alone, DR is of little value, & map reading is limited, but when used in combination, they form the basis of all navigation. One might say that map reading is an aid to Dead Reckoning; or vice versa.
It is easier to consider only the cruise portion of a flight, although the Aero Navigator must include wind & air speed effects during the TO, climb, & descent phases of the flight.

For VFR flight only a Sectional chart is required, although if he holds an instrument rating & the plane is equipped & certified for IFR it would be prudent to carry & preflight for IFR in case the weather degrades enroute.

The Aero Navigator should obtain intermediate winds if the flight is long, or there are weather systems that might result in major wind changes; or require flight changes enroute. In the below table it is obvious that winds vary along the route. He must establish how to treat such large variations. With such large wind variation a simple average would not be desirable. The use of average W/V would cause the plane to swing off course, although it does have the advantage of not requiring frequent heading changes. Another disadvantage in averaging W/V is that departure winds might hold steady for 80% of the flight, invalidating the averaging technique. If averaging is employed it would be wise to at least use a series of winds, or a weighted average.

If magnetic variation changes appreciably on the flight, it would have the same effect as W/V changes; though to a much smaller extent. However, if the Aero Navigator wishes to stay as close as possible to the true course he should plan to apply actual W/V frequently and also monitor & correct for variation.

Altitude in Feet	*Departure W/V*	Temperature In °C	Destination *W/V*
6,000	150/35	+11	230/30
9,000	150/35	+6	210/30
12,000	130/45	+2	210/35

The Aero navigator first uses DR & his Sectional chart to preflight the trip. Departure and destination airports are plotted and the true course should be lightly-temporarily drawn between them. He must review the Sectional in case he needs to deviate. Examples could be the irregular shaped Mexico-U.S. border, a Restricted area, thunderstorms, Lake Michigan between Grand Rapids & Milwaukee, that he prefers to circumnavigate. If he plans to cruise below 10,000' he may be forced to deviate around Class B airspace; very large airports. Once he establishes the deviations he must redraw the course line, & preferably mark occasional distance values. If the flight is to be a "Round Robin" (out & return), he may choose to write distance to & from destination on opposite sides of the chart; possibly inverted on 1 side. The Aero navigator must measure the true course & the distance. He must compare the distance with aircraft nominal range to determine whether a refueling stop may be necessary. That analysis may need to be repeated after he applies the winds.

On a flight with several legs, or dog legs, each alter point and each course line should be constructed.

Takeoff time, climb speed (IAS), climb heading (preferably CH, MH, & TH), & other changes during the climb must be logged, as well as frequent fixes. GS should be computed for each phase; preferably even during a long climb.

Time, altitude, heading & new IAS should be logged at level off. An immediate map reading fix should be documented. Frequent map reading fixes should be logged with time since TO, & new computed GS, as the flight progresses. Upon the determination of a new map reading fix the navigator should compute GS & the distance to the destination from the fix, & a revised ETA.

If instruments show stable conditions, & GS remains uniform, the frequency of map reading fixes can be reduced. An occasional deviation check is worth the effort since a ground check (compass swing) may be subjected to external influences.

There is no set rule to guide the Aero Navigator in taking deviation checks, however a good rule to follow is to obtain an initial deviation check, and an additional one each time the compass heading changes by more than 45°. Frequent W/V computations are recommended if any changes in drift or GS are noted.

For plotting courses it is good to have a shorthand or other standard shortcut nomenclature. One convenient method includes a circle with a dot in the center that is precisely the location of a DR position. A fix might be indicated by a triangle with a dot in the center; an air position (airplot) might be indicated by a cross (+).

Map Reading is useful day or night, but obviously not if above a solid overcast. VFR above even a broken layer of clouds is certainly not recommended. There is actually an exception to the "overcast" limit; covered in a later Aero Nav system in this series. It's fun, a challenge, & a confidence builder, to fly a few hundred miles by dead reckoning, & then to try to establish a fix using only DR & a Sectional Chart. If in doubt, keep a VOR tuned to a VOR near the destination, or along the route, with the OBS set for a meaningless reading. The proficiency gained may ease the pain if a loss of primary Navigation aid forces the Aero Navigator to resort to less user friendly Aero Navigation systems. It may even prevent an emergency landing in the future.

4.3.4.1 Sectional Chart Legends:

Fig 9 depicts the Sectional Legend. The top left symbols are identified as relating to airports. Airport variations may include some that the plane or pilot are not equipped for, such as seaplane. Orientation of hard surface runways are shown. In some cases an airport may have both hard surface runways & grass strips, in which case only the hard surface runway will be shown. An airport diagram such as in the AOPA airport directory will have runway length for other runways. If information is important, the diagram can be pulled up on the internet. A call the FBO or airport manager is another option

To the right are items called airport data. Depending on the type of plane & avionics, & the weather, the Aero Navigator - pilot may not be interested in some of the symbols, but it is important to be able to identify them. Some may prohibit operation of specific planes. Others may even identify runways that are too short for the plane being flown. If flying a limited power plane, the field elevation may be a concern. See Note 1 below. If flying at night, some airports are not equipped with lighted runways. If the weather is marginal VFR, & either the pilot or plane is not current & certified for IFR operations, the Aero Navigator - pilot may prefer to avoid airports with "no SVFR" since special VFR operations are prohibited where the "no SVFR" note is found. "Special VFR operations" refers to the allowance of take-off & landing operations somewhat below VFR minimums. Two of the most important items found on Sectional charts are the runway length & elevation. Runway length is always given in hundreds of feet, & elevation as an integer. Runway length of 7,200 ft would be printed as 72. Elevation is listed completely; such as 285 ft. Actual field elevation is shown at the airport symbol.

Note 1: The author once landed at a small airport NW of El Paso in his brand new Cessna, & saw a cute (or ugly?) little 2 place externally wire braced Aeronca C3 (from the early 1930s) powered by a 36 hp 2 cylinder horizontal opposed engine. An airline pilot had landed it there, & was unable to take off because of the high density altitude. It was CAVU (ceiling & visibility unlimited), as usual for the desert Southwest, but a pretty warm day when he left it, & the elevation was near 4,000'. The 2 cylinder 36 hp engine was obviously inadequate for such a high density altitude. At that time the author routinely few the wonderful Piper J3 Cub out of a higher elevation airport. No doubt about the benefit of the 65 hp vs. 36 hp engine. Several years before the author had seen an Aeronca C3 try several times to lift off from Marshall, MO (elevation 779) with 2 very heavy men aboard. They even tried jockeying the stick to institute a series of bounces. Once airborne the drag would have been lower, but with such limited power he may have had trouble clearing the fence at the end of the runway. The Aeronca K model was similar in vintage, power & performance to the C3, but looked more modern; much like a miniature Taylorcraft BC-12D. Marshall, MO had been an extremely prosperous aviation community in the years just before Cessna & Beechcraft settled on Wichita KS for their headquarters. Porterfield was one of several early aircraft manufacturers with manufacturing facilities at Marshall. History showed that Marshall was expected to be the center of the nations General Aviation manufacturing in the U.S. Beazley Aircraft parts was located there. They expanded to design & manufacture the very large Beazley monoplane that soon set an impressive nonstop distance record. Actually Beechcraft was still building one of the greatest biplanes of all time; the Staggerwing Beech (200 mph cruise; radial engine powered); & was located in Wichita. The "death of the biplane" as the mainstay of aviation had already largely occurred. Cessna was, after all, the pioneer in cantilever monoplane development at the time that Wichita was selected. The term stagger (from Staggerwing Beech) meant that the wings had reverse stagger, vs. the normal stagger; the upper wing was behind the lower wing instead of in front, per the norm. The reverse stagger did improve stall performance. Although it was a large plane, the wing span was only 32 ft, vs. at least 36' for most 4 pas monoplanes. At $17,000 vs. $2,500 for a Cadillac, introducing the Staggerwing was quite a gamble during the height of the depression, in 1932. Manufacturing finally ceased in 1948. With a range over 900 miles & a ceiling of 20,000', it carried 5 people in luxurious comfort. It was powered by the majestic Wright radial engines having power between 225 & 710 hp (mostly 450 hp). Fewer than 800 were built, but many are still treasured by proud owners who are younger than their Staggerwing; most still airworthy. At 2,570 lb empty & 4,270 max gross, it was heavy, though light for its large radial engine & high performance. There is an impressive Staggerwing Beech museum in Tullahoma, Tenn.

Any Aero Navigator will be interested in "radio aids to Navigation", as well as several other types of symbols that are defined. Obstructions such as tall towers are especially a concern in low visibility conditions.

Failure to learn the chart symbols, & to refer to the Sectional, could result in hazardous operations, or a violation of FAA regulations, such as penetration of restricted airspace.

Referring to Fig 5, the city of Houston is shown as a large yellow area with few details included. Note that this figure was also enlarged. Just to the right of top dead center is 100/SFC. This represents the vertical limits of the Class B positive controlled airspace around IAH (Bush International Airport); surface to 10,000'. Height of 10,000' is the norm for the top of Class B airspace; terminal area for large airports. No one is allowed to fly within the 10 NM radius heavy blue circle around IAH without clearance from the FAA (approach control, center, or the control tower).

Not far from the bottom right is the same 100 / SFC for the same type circle around HUB (Hobby) airport. Back toward the top left is a 100 / 200 indicating that between the inner circle & the 20 NM radius circle, flight is controlled between 2,000' & 10,000' altitude. Note the large number of tall & moderate height towers. Altitudes are given in MSL (mean sea level).

4.3.4.2 Map Reading in Congested Areas:

Flying into Hobby or IAH would require positive control, & usually "vectors" by Approach Control & then the tower, so map reading would not likely be employed. If, however, the FAA controller instructs him to, the Aero Navigator must be alert & ready at all times to "resume his own Navigation".

Flying into any of the smaller airports near Hobby would require accurate Aero Navigation. A GPS, LORAN, or OMNI, or even an ADF (preferably by homing in on a radio beacon) may be preferable to map reading, though map reading is excellent, & the map reading skill is essential.

If the best available Aero Navigation system to the Aero Navigator were map reading, the Aero Navigator would rely only on DR & terrain features that are shown on the chart. DR, as always, is necessary in map reading. Imagine flying 300 NM of a 500 NM trip without the use of DR to establish GS & drift. Do assume, though, that he remained aware of his position by map reading, & stayed on course; but remained unaware of the effects of wind; as though there were no wind. He would not realize that he had a 20 kt headwind component, & also a 15° left drift. He would assume that he should have traveled 300 miles at his 100 kt TAS, & remained unaware that he was correcting for drift. He would know that he has a 600 mile range at 100 GS. Suddenly he sees a large squall line ahead, but thinks he can alter 30° to the right to avoid it, fly 1: 09 (1 hour & 9 minutes; 1 hour / cosine 30°) at 100 TAS (thinking it's also GS), then alter 60° to left & arrive at destination in another 1:09 (1 hour & 9 minutes).

The E-6B shows that the facts based on the above will result from a 57° / 31 kt wind. With his actual drift, & this wind, he will travel 116 air miles in 3:45 in order to reach his 300 mile fix. After he alters from 15° to 45°, the new TC will actually be 40°, & GS will be 70. His assumptions on 1:09 at each of 2 new headings [will eventually result in arriving at his ETA (3:45 + (2 x 1:09)] 66 NM to left of course, & 91 NM short of a point abeam of the destination; 118 NM if turned to correct heading to head directly to destination. Of course, at latest ETA he would be in the air for 6:03. At 70 kt GS for 1st 3 hours, & 80 for the next 2:18, he will travel 262 miles to 300 mile point, & 184 in different directions, for equivalent of 160 in intended direction of flight. He will essentially run tanks dry at the above 184 miles from destination. Hopefully no one will be so inept as to fly as described in this example, but it does prove the importance of keeping up with position, actual GS, W/V, etc.

In fact, larger airports usually have an enlarged chart that is devoted to a moderate sized area to provide greater detail; but not for map reading. Referring to the chart of Fig 5 he will see that map reading would be limited; not many identifiable land features. He should closely monitor his position as he flies past or along highways or other features so that he knows exactly where he is at all times. If his position is over the "100 / 20" near the top left of this figure he would be allowed to fly up to 2,000' altitude; or fly above 10,000'.

If he were flying into Clover airport, near the lower right of this portion of this limited Houston Sectional, he'd have a few concerns. Clover field, incidentally, shows only 1 hard surface runway, but it actually has 4 grass runways that are not shown; quite an airport. Tires last much longer if flown off of grass strips; one reason for their popularity. A direct flight would place him near Hobby, & well within the disallowed "surface - up" area. He should draw the route directly on the Sectional chart in order to properly navigate by map reading. Note that he would not follow airways for the proposed route. The best route might be a "dog leg" from the "100 / 20" point to a few miles East of the 2,049' tall towers, but continuing on that course (about 162° magnetic course) until crossing a line between Clover & “Flying B” airport to the West, & slightly South of Clover field, & then turning directly toward Cover field (about a 080° magnetic course). Flying near the tall towers would not be as bad as it first appears because the wide blue line represents the boundary between “surface-up” & 2,000’ Class B airspace floor. A course that is tangent to the compass rose which has inside a series of radial hash marks at 5° increments, would be a safe route to follow. The compass rose, of course, is not visible on the ground, so a little map reading is in order.

What would be easier, as he neared the towers, than to positively identify all 5 tall towers, & stay a safe distance East of them? A good choice might be to fly at 1,800’ & also positively identify all shorter towers, & fly nearly directly over the lowest, Western-most 583’ tall tower. Alternately, remember that the towers are not readily visible when flying over them, so the 974’ tall building is much easier to see & identify than towers. In either case, height is given in MSL. Since the plane should have a current altimeter setting, the altimeter will also read MSL. When flying in the vicinity of towers it is prudent to avoid flying too near them even if several hundred feet above them.

Always keep obstructions in sight in case of an engine problem, or a need to avoid “threatening” traffic. More importantly, if flying below the top, as with the 2,049’ towers, always fly several hundred feet, if not thousands of feet to the side, to avoid guy wires. As he passes the 583’ tower or the 974’ tall building, he should look for another positive fix. The major highway shown closely paralleling the lower (Southern) edge of a large yellow mass (city of Houston) is a multilane divided highway; or freeway. In fact, it is many lanes wide outside of the highway 610 West Loop. It is "Highway 59". The racetrack on the South side of "59" may not be very conspicuous, & might even have been overtaken by residential developments recently, so may not be an ideal fix. Highway 59 does turn sharply (nearly 45°) toward the North. It is quite obvious to a map reader. Further, if he drifted to the left of his intended route, he would violate the “surface-up” portion of Hobby airspace. He must then pass several miles to the West of that bend. He should fly his hand drawn route, & measure the distance abeam of the highway 59 bend; just to be sure he clears the Hobby “surface-up” boundary.

He may measure the distance from the 2049’ tower to the final leg toward Clover, & time the point he should reach the intersection of these 2 legs. If his DR is accurate, that should be acceptable. If in doubt, increase distance from the “surface-up” Class B airspace boundary. Possibility of a mid air collision in case of an incursion would be negligible, but it could conceivably result in a discussion with the FAA about a “minor” violation. He should soon cross the Northbound divided highway (No. 288; he must measure so he will know how far & how long); & the distance & time to reach Clover field, too. Before departure, or reaching the initial point in this example, to facilitate his Aero Navigation by map reading, he should have requested the surface & 3,000’ winds from FSS. Then he should have computed W/V (if not received by radio), drift & GS based on an intelligent guess of 1,800’ W/V, or assumed that 3,000’ W/V applies at 1,800’ reported between, so can apply them to the final East bound leg. At 2,000’ the winds should be much closer to the 3,000’ winds than surface, since the friction effects generally provide an asymptotic wind change. He will look for Clover & the 2 small airports to either side of the route, & more importantly, the 1 he should pass directly over, if still at 1,800’. Much better to give that field a wide berth to clear any planes in the traffic pattern, as well as looking for such planes, & monitoring UNICOM for traffic being reported. Conversely, it is quite probable that Approach Control will prefer to monitor & vector him during the entire flight as described here. In that case they should keep him clear of pattern traffic; or advised of same.

In congested areas the Aero Navigator should be alert for large airports; most of which are tower controlled. Entering their airspace requires that FAA contact be established; sometimes FAA approval is necessary. Airport runway layout is also informative for Aero Navigators. Houston Hobby has a classical runway layout: Runway 35-17 forms the hypotenuse of a triangle with the other sides of 30L-12R & 22-4. 30R-1L are parallel with the other (30L-12R) runway. The runway numbers are always the compass direction with the last digit omitted. L & R indicate parallel runways. As such, the L & R are obviously reversed on a given runway. In the case of 30R & 12L it is obvious that headings of 300° & 120° are opposing directions on same runway. If 12L is left of 12R, then 30R is the same physical runway as 12L; reverse direction. Two of the 4 runways are over 7,600’ long. It is interesting that New York La Guardia has only 2 runways at 7,000’. JFK has 4 runways, which are longer than those at La Guardia. Although low level flight close enough to visually establish runway layout is not permitted without FAA contact & instructions, it is still interesting to note the importance of identifiable differences.

4.3.4.3 Map Reading in Sparsely Populated Areas:

A little map reading in a more isolated area would also be informative. Fig 12 covers a portion of the Albuquerque Sectional near the Mexico-New Mexico border. Plan & fly from Deming airport (DMN), New Mexico to Lordsburg airport (LSB), New Mexico, & then up to Whisky Creek airport (94E) at Silver City, New Mexico; all by map reading. Note that although there are VORs & associated airways near 2 of the 3 airports, none precisely cover any of the legs. It would be advisable to check each airport for services, in case of a need to refuel, or on extremely rare occasions, problems. Modern planes are typical of GM cars; “bullet proof”; meaning maintenance free. The author had only 3 cases in most of his 4,600 hours in Cessnas & similar planes where he needed to delay take off or land prematurely for magneto or similar problems. These involved no risk of an actual emergency landing. He has made 3 emergency landings in his many years of flying. One because of a hazardous faulty teaching (mentioned elsewhere) by virtually all of the flying public that can under some conditions cause carburetor ice. Another by a careless mechanic that resulted in an engine shut down to prevent damage from loss of oil pressure & a dead stick landing from 10,000' with little extra altitude. The third was previously mentioned from a series of deceptive factors that resulted in fuel starvation. Three emergency landings among over 8,000 landings total There were several other "expected" dead stick landings in a sailplane. These dead stick landings were safer because the author nearly always reduced power to a full idle for landing approaches in any plane flown; which improved his ability to touch down at a predetermined point.

4.3.4.3.1 Preparation for flight is more critical in Sparsely Populated Areas:

First draw a TC line for each leg. The easiest way to measure course direction is to use the OMNI compass rose, which provides MC (magnetic course) rather than TC. Since the CH, rather than the TH, is what is actually “visible" (on compass), the OMNI compass rose, MC, & MH are important for the preflight. In that case a pair of dividers could be used in lieu of the Weems plotter to measure distance; by transferring to the Sectional mileage scale.

The next step is to measure MC or TC, & distance for each leg. The leg from Deming to Lordsburg is 263° MC & slightly over 49 NM. The leg from Lordsburg to Whisky Creek is 032° MC & slightly over 36 NM. Actually, the TC is unnecessary since the compass reads magnetic rather than true values. Since this is a map reading course, OMNI - VOR is not available for this trip. A direct line is satisfactory. Compute time for each leg based on anticipated TAS, corrected to GS if winds are known. Apply drift & magnetic deviation to each MH to determine desired CH (compass heading). Note that the TAS must initially be assumed from prior experience at planned altitude & power setting. Once at altitude in cruising flight TAS can be computed as in Fig 15 by use of IAS (CAS) & OAT.

It is not mandatory to fly airways for VFR map reading. Victor Airways were initiated in 1921 & expanded until they included 45,000 miles by 1952; as the FAA began decommissioning the low frequency ranges. Following airways is not mandatory. Airways were, for many years, a convenience based on several nav aids that are located at specific points around the U.S. There are, however, several valid reasons to fly airways, including safety & simplicity.

IFR was always restricted to flying airways until in 1969 when 16 “area Navigation routes” (RNAV; Aero Nav system no. 31) were temporarily commissioned. By 1990s “free flight” (RNAV) was reestablished. They now permit flying directly between departure airport & destination airport. Previously IFR flights were required to fly directly to or from VORs. Area Navigation (RNAV) became practical thanks to more accurate & flexible Aero Navigation Systems. RNAV is of great value because it reduces flying time & distance. It reduces or eliminates alters, flight time, distance, & even traffic congestion.

4.3.4.3.2 Studying map before takeoff is more critical in Sparsely Populated Areas:

Especially if unfamiliar with the route, it would be wise to study the map to locate potentially useful fixes. It is obvious that there is a limit to such features in such a sparsely populated area. There is a unique very small restricted area (R-5115) not far from the Mexican border. There is little indication on the ground that it exists. The small box near it clarifies its purpose; unmarked balloon up to 15,000’. It was a shock the first time the author & his wife saw the balloon near their altitude, even though they knew where it was.. The cable was unmarked & barely detectable; obviously not resolvable. Many years before, soon after receiving her private pilot’s license, the author’s wife took pride in her exceptional map reading ability in such barren country by use of arroyos, dry rivers, ranches, dirt pathways, & similar nearly inconspicuous symbols. It may be surprising just how easy it is to map read with so few landmarks.

Departing the Deming airport, winds would most frequently be from the Southwest. FAA regs require planes to fly a minimum of 1,000’ above the highest obstruction in congested areas (town, etc). Depending on aircraft climb & take-off performance at 4312’ elevation; potentially at a much higher density altitude if as hot as it might be in Deming, it may be preferable to deviate away from the city immediately after takeoff. It is permissible to fly lower on takeoff, just not desirable. Although 100° F is quite comfortable with the dry air at Deming, & that temp is seldom experienced, high temp does influence air density. Lower air density reduces take off & climb performance, as is discussed in detail in Appendix F**.** Even though humidity in Phoenix, Arizona is much higher than in the nearby desert, the author found once found 112° F on the hot asphalt ramp tolerable on an unusually hot day; quite different from high humidity areas.

Assume a SW wind, & a takeoff on runway 22 (for 220°; vs. 225° for a SW heading; note that runway numbers are in fact, direction less the last digit.). Assuming that there is no other traffic, & the pilot elects to turn to 263° MC as soon as clear of the Southern edge of the town of Deming. As he passes over the S. side of Deming he should note his position relative to the divided highway & railroad track & compare the shape of the "yellow" area with the city streets & structures. He could even note the obvious entry angles & curves of the highways & railroads on all sides of Deming. Those relative locations & curves all the way around Deming are unique to Deming. He will certainly not find another city with that exact configuration of roads, etc. If he were uncertain of his location, & enroute to Deming, or just passing over it, he could easily identify it as Deming.

This series of land features proves just how simple & reliable map reading can be.

A quick sketch of an adjusted course would be useful; from the South side of Deming it would show that he should cross the railroad 7 NM from the runway intersection; possibly from lift-off. At that point he will be nearly 5 miles South of a small mountain that is about 1,000' high vs. airport elevation. He should use his best known GS to compute the time that he should cross each identifiable fix along his route. He should be 42 NM from the destination as he crosses the railroad. Considering the shallow angle of crossing, the exact time & point of crossing is subject to possible serious error.

Crossing the 108° meridian, & 14 NM from Deming airport he should see a small "tank", & some small buildings 1 mile South of his adjusted course. The underground pipeline (shown as a dashed black line on the chart) that runs very close to the intended track may be detectable. If it is, it would certainly greatly simplify map reading on this leg. Just 6 NM after passing the tank he should cross a road 1 NM N of the pipeline, & 2 NM N of the "Y" that is formed by another road that he crosses 7 miles after the tank. That "Y" is only 1 NM North of a divided highway (Interstate 10). He should even be able to identify the ranch 3 miles West of the "Y". At that time, not much further to the right he should see another small mountain, & note rising terrain & small stream; possibly dry as he crosses it.

The above illustrates the fact that map reading is not limited to "Ideal" locations.

When "abeam" of the very small town named Wilna, which is 5 NM South of course he will be 24 NM from the Lordsburg airport. Abeam meaning, "when a point is directly off of either wing; perpendicular to the longitudinal centerline of the plane". Looking exactly to the left, if following a track 1 NM North of the pipeline, Wilna should be clearly visible.

Although 5 NM visibility is not uncommon in much of the East & West coasts, it is rare to find visibility less than 100 NM in the beautiful desert Southwest. In fact, from as little as 1,300' altitude, the destination could be seen from over the departure point. See line of sight table; Fig 27, which shows that the destination, though not positively identifiable, at 49 NM, could be seen from over Deming airport at about 3,000' AGL (above ground level). Note that the most commonly used & important aviation radio frequency, VHF (very high frequency), transmits in a straight line, so Fig 27 applies to VHF as well as visual observation. Fig D-9 illustrates details of the various frequency bands.

Aircraft Visual Line of Sight vs Altitude						
Also VHF Radio Altitude vs. Range						
Altitude AGL	1000	2000	3000	4000	5000	10000
Visibility or VHF Range:	39	43	48	52	57	125

Fig 27: Altitude vs. Line of Sight & VHF Radio Frequency Receiving Range.

With 17 NM to go, he will see a railroad less than 1 NM North of a divided highway (I- 10; an interstate highway), both making a sharp turn from a direction of 248° to 290°. Although well South of his course, it affords a useful fix. A short ways later he will cross a narrow paved road, & then a power line that runs North to South; 9 NM before reaching Lordsburg airport.
With 3 NM to go he should cross I- 10.

After a "business" stop he might call FSS for an update on NOTAMS & weather before hopping off & head for Whisky Creek.

The Lordsburg airport has a paved runway; number 12 - 30, & is 5,086' long, & adequate for nearly any lightplane at 4,278 elevation, but if W/V is 235 as is typical for that area, it's 65° off runway centerline. If W/V is over 30% of aircraft stall speed, it would be preferable to use the dirt strip that crosses the hard surface runway. But on runway

1 - 19 the crosswind component would still be 45° of centerline. A consideration that may be of concern with lower powered, or high stall speed planes, is the rather short runway; 2,655'. If the wind is light; for example 5 kt, the pilot would probably elect to take off on runway 30; 300°. If his climb performance is adequate he would probably turn 92° to the right, onto his 32° course, as quickly as allowed to avoid flying low over Lordsburg, & keep him close to the planned ground track. He will almost immediately see & cross I-10 & then the railroad track & the I-10 loop around Lordsburg. Then at 6 NM past the airport he will cross the pipeline, & at that time he will see a power line about 1 mile to his right, & he will be on his way.

If he stays on his intended course he will pass directly over a 6,951' peak 9 NM after takeoff. This would also place him further from the next peak (7,048'). It is also best to fly West of the next peak (8,040'). He should also monitor the wind direction & speed. He should avoid flying downwind of any mountain; especially if he is less than 2,000' above it, to reduce the risk of severe downdrafts. It is wise to deviate around peaks on the upwind side of mountains, so that he might take advantage of "slope thermals" (updrafts generated by air flowing up a slope) instead of losing altitude in downdrafts, as well as to increase ground clearance. It is much safer to fly with ground clearance greater than 2,000' in mountainous terrain if winds are light. If strong winds exist, it is best to either wait for lighter winds; or deviate toward lower elevations. It is possible to experience 2,000 ft per minute up or down drafts in desert or mountainous country. Very few lightplanes can out-climb such downdrafts.

An important but simple solution to reduce the altitude loss in severe downdrafts is to accelerate (drop nose somewhat) through downdrafts to reduce time in the downdraft, & slow down to benefit for a longer period of time from updrafts. Controllers are likely to call to advise of large altitude changes; certainly if IFR, but this simple tactic certainly will minimize deviation from assigned altitude. If VFR it is preferable to use this method to stay at or above intended altitude. If necessary to lose altitude it is more efficient to do so by slightly lowering nose for a very small IAS increase.

Noting the apparent or relative heights of peaks, & their relative locations will confirm the position at any given time & location. This mountainous route, with no long straight "section lines" or roads confirms the value of orienting the chart with the direction of flight. Imagine turning the chart with North straight ahead. The 32° course error may seem close enough, but it would certainly confuse anyone. If a peak is directly to the left, & another directly to the right, the 32° difference would certainly result in confusion.

Several roads are in view along his route. Time of crossing will depend on how far he deviates from direct course. If approaching from West of direct route he must avoid traffic area of Turner (private). He should be cautious for the tower NE of the destination airport.

Note that it is 1 NM from the airport, 206' AGL, but ground level at the base of the tower may not be the same as at the airport. A word of caution: ROC is seriously reduced at higher altitudes & even more so if the temperature is high. Note that only a few miles North of the airport the mountains are considerably higher.

As he approaches Silver City he should observe the city & the unique pattern of roads & size & shape of the city. Although there are not many towns near Silver City, it is always possible that a similar road configuration would match well enough to deceive the Aero Navigator. Taking note of the length & width of the yellow, & also the exact shape might alert him to an error in his selection.

When crossing a mountain range it is advisable to cross at a 45° angle to reduce the amount of turning required if experiencing unexpected downdrafts. As above, mountain crossing should be limited to moderately calm winds. If W/V exceeds 20 kts great caution should be exercised.

If a change of plans calls for flying from Silver City to Gallup, a detailed review of restricted airspace, mountains, & airways would be advisable. The diagonal line cutting across the top left of the "scanned" portion of the Albuquerque Sectional has a series of closely spaced hash marks as an indication that the airspace inside (above the line) the enclosure has some restrictions. Similar to the round restricted area discussed above. Color of lines of this new airspace indicates MOA (Military Operating Area), while the small round area line color indicates a restricted area. Either could be continuous, at specified times (such as sunrise to sunset), or at times obtained from the military via FSS. There are, in fact, 3 separate MOAs (military operating area) above Silver City. Another concern is that there are no airways to the North of the Silver City VOR, except 1 at a 36° MC (magnetic course). That may be because the MOAs are continuous, but possibly that the terrain is high enough that many planes could not safely fly over it. Since airways also serve high performance planes, that is unlikely to be the reason. It is possible that there are no cities large enough to justify airways located in that direction. If the MOAs do not permit flight at the time you expect to fly to GUP, a review of charts would indicate whether the best route is to the East or West.

If the plane in use has limited performance, some routes to the North out of Silver City may not be practical. A service ceiling of 15,000' would be desirable. A look at IFR (Enroute) charts would be wise. MEA, MRA, etc would establish safe altitudes for any airway. Enroutes give specific types of minimum acceptable altitudes for airways; as is discussed in detail elsewhere in this Aero Navigation series.

The route from Deming to Silver City may be a case where flying is not shorter than driving. Typically flying saves 10 to 20% of the highway distance between any 2 cities. An excellent example of this is the route that the author & his wife has flown many times over the years; usually at least twice per year; (T41) La Porte, TX to GUP (Gallup NM). The shortest road distance has too many towns, & too much without limited access; 1,100 miles, but it actually takes longer to drive than the more deviant route. Via limited access freeways the drive is 1,200 miles, but a little faster, much more pleasant & safer. Due West on I -10 to El Paso, North to Albuquerque, & West again to GUP. Flying is essentially direct, & only 900 statute miles. That represents a 25% savings; the equivalent of cruising a slow plane at 120 kts while actually cruising at only 90 kts. That flight permitted taking off at 7 or 8 am & landing at GUP near noon; time to visit with & buy from her favorite Native American artists, & 1 trusted wholesaler before the end of the day. This vs. 2 easy days driving or 1.5 days of hard driving. Airlines take nearly the same time considering the longer drive to the airports & long early arrival times required in 2010. At least Southwest Airline has vastly better protection & allowance for the large, expensive (Indian jewelry), fragile baggage for the return trip. Another merit with Southwest is that it is employee owned, so the commonly reported luggage theft is virtually non-existent with Southwest, since any employee witnessing theft would report it.

Note the very large blue numbers spaced about 25 NM apart. The small number represents hundreds of feet, & the large number represents thousands. This is an excellent safety measure; eliminating the need to search the entire route for mountain peaks & tower heights. The number indicates the highest known obstruction, including tops of towers, within that small quadrant of the Sectional chart. South of Lordsburg the 7^4 then indicates 7,400'. North of Lordsburg the highest known obstruction is 8,000', & toward Silver City it is 9,400; but still further to the East it is 10,400'

A careful look at the shading & colors of the mountainous areas is justified. If it is deemed safe to fly direct, & MOAs are open to air traffic, a simple way for a map reader would be to follow the road that departs to the NW from Silver City. It does avoid some of the taller mountains. Conversely, the author opposes following highways; prefers going the shortest, direct route. It also sharpens his map reading skills.

Is it likely that an Aero Navigator might confuse 2 small towns? Or 2 landmarks? To eliminate that fear, look at each of the Sectionals shown here. Imagine a circle with a 25 mile radius. Note that scales are always constant on Sectionals, but these illustrations vary because of the author's intent; some are scaled up or down. If tired after a very long day of map reading, or simply doing a sloppy job of map reading, an Aero Navigator might actually be 10 or 20 miles off course. Compare towns or other landmarks of any one landmark with all other within that 25 mile radius circle. It should be obvious that there is no feature that could be mistaken for another.

A More Explicit Example of a Map Reading Flight:

An enthusiastic 150 hour (experience) pilot convinced his new wife that a flight from Houston TX to Los Angeles would make a fitting honeymoon. He could really experience his new toy, & hoped she would find this to be a fascinating, enjoyable & liesurely flight. She was able to tolerate the tiny baggage compartment; not much larger than the saddle bags (boxes) on the beautiful reliable Harley Davidson motorcycle that he'd traded for the plane. His plane is a mint condition antique 1946 Taylorcraft BC 12D, powered by a 4 cylinder horizontal opposed 65 hp Continental engine that requires hand propping. It cruises at 95 mph. Even such an old, slow pane was faster than driving, & much more enjoyable, with vastly better view, & the ability to circle mountains or other attractions. This was to be the 3rd leg of the long flight. They would cruise from El Paso Int'l airport (identifier ELP; 3958') to Whiskey Creek airport (identifier 94E; 6126') at Silver City, NM with a dog leg at the Deming airport (identifier DMN; 4314). Field elevations are listed in parends after the identifier. He had verified weeks before that the plane will safely take off with their load at the likely temperature & field elevations. He knew that the T-Craft service ceiling exceeds the expected cruise altitude for safe terrain clearance. Actually because it has a larger wing area than most 4 or even 6 passenger planes, it has an exceptionally high service ceiling of 17,000'. He was pretty thorough, but forgot to check winds before T.O. Since he had no avionics at all, he could not check winds in flight, nor fly the airway via OMNI. His Aero Nav capability was limited to DR & map reading. No problem. To fly that plane he was forced to remain sharp at both, but so should all pilots. He didn't mind, but was forced to do his own Aero Nav since his new wife was not yet familiar with either. He was so distracted by the beauty of his wife & the mountains & desert on his first flight West of Houston, that he assumed his heading was OK. He finally picked up his Sectional as he expected to be approaching Deming. He knew in advance that the first leg was 76 NM, & the second leg 39 NM. He also knew that the MCs were 273° & 309°. His TAS was 82.5 kts. When he finally checked GS & drift, as he passed abeam of the Deming airport & turned from 273 to 309°, he was 2.5 to 3 NM left of course, so his drift was 3° left. He quickly computed GS with his E-6B. The first leg took 58.5 minutes, so his GS was 76 kts. He immediately computed W/V with the E-6B to be 256/5. Then as soon as possible, before he had flown a potentially seriously incorrect MH, he entered TAS & W/V to find that he should fly 306° to correct for the 3° right drift. He predicted a new GS of 79 kts & time to be 29.6 minutes. The decimal minutes are optimistic, of course, & he did need to make a proper traffic pattern before landing. He landed at Whiskey Creek after 1:35 in the air; ready to see the sights in & around the historical Silver City. Seeing Whiskey Creek is reminiscent of the author's roots. His grandfather's farm was located on what was the "Rascal Flats" area near Salisbury, MO; named during the Civil War; for gangsters who camped there for a few years. The music group called Rascal Flats actually named their group after his cousin's "4 wheel drive parts" business on that property; also called "Rascal Flats Truck Parts".

4.3.4.4 Map Reading at Night; & an Official Misconception:

A popular misconception was finally positively dispelled several decades after WWII when all internal lighting was red. The errant concept was that red light did not reduce the night vision of the human eye as badly as white light. The fact is that the absolute intensity is the key factor. If red light is provided with sufficient intensity to read maps, etc, it is as detrimental to night vision (seeing objects on the ground) as white lights that are reduced to the same absolute intensity.

A serious detriment to the use of red light is the loss of much of the ability to detect colors on Sectionals. Many details are no longer detectable. The author immediately removed the colored filter on his instrument panel light long before it was public knowledge. He used the existing rheostat for precise dimming control. It is also a matter of preference, but he prefers a single overhead light with custom shields to block the light from the windshield, etc. Individual instrument lights are delicate, inconvenient, & seldom seem uniform.

Night map reading is more demanding than in daylight. Obviously the roads & many other things are much more difficult to see than in daylight. Highways certainly can be invisible if there are no headlights to see as traffic decreases, such as after midnight. Likewise, in lower traffic areas. Large cities & highways carrying heavy traffic have many headlights to illuminate highways. Buildings are often well lighted. A concern is that large black areas may not actually represent unoccupied spaces; they might be large bodies of water forests, etc.

Seasonal changes alter appearance of various objects, so must be interpreted; especially with changes from green vegetation to snow cover. Add to that the possibility of lakes freezing which appears to be shoreline shift.

City shapes are usually as unique with lights as in daylight. As always in Aero nav & flying, redundancy is essential. Never accept just one check point (feature). Identify nearby landmarks.

The moon or assorted lights can briefly reflect off of large bodies of water & rivers to aid in determining position. The author has flown a few very long XCs at night using only map reading, with less difficulty than expected. Night map reading does require closer attention, & tolerates fewer mistakes.

Appendix B has pertinent comments on safety issues re night flying. Night map reading may be particularly difficult in sparsely populated areas, or in isolated recreation areas such as lakes in wilderness areas, fishing spots, & small airports. Some areas in the mountain & desert states can occasionally be nearly void of lights, especially after 2 a.m.

Map reading is vital in approaching an airport, day or night. It is essential in the event of catastrophic electrical system or multiple Aero Navigation system failures. Airports are easier to locate from afar, & quite easy to identify at night with assorted specific lights; especially larger ones with sequenced lead-in lights Conversely even airline pilots have occasionally mistaken lighted highways for runways. There are relatively few lighted airports to choose from for night flying.

It is particularly important to keep an accurate track of position throughout a night flight, & to document each fix. Equally important is to compute & record GS & W/V frequently.

4.4 Aero Navigation System No. 4: High Intensity Light (Beacon) Tower Airway System

4.4.1 The Evolution of the Airway System included lighted towers.

In the early days of flying there were few actual airports, & neither rules nor guidelines as to how to travel between any 2 points. Pilots often landed in farm fields near a town that may have fuel available. They offered plane rides to people who may have never seen a plane before to earn money with which to buy fuel.

Initial attempts at establishing airways were designed by the U.S. Post Office, primarily for the Air Mail pilots who "rushed the mail across the U.S. at break neck speeds", day or night, in good weather & bad. In fact, Lindbergh once bailed out of a biplane that was carrying mail. The plane circled him in the dark, engulfed in the clouds during a snow storm; until it crashed.

Those landing sites along the earliest airways were illuminated by car headlights & bonfires placed at 10 to 15 mile intervals, in 1919; with very limited success. By 1921 they began installing a few electric beacon lights on towers. Beginning in 1923, the U.S. Post Office rushed to complete a transcontinental airway of beacons on towers spaced 15 to 25 miles apart. High brightness, or candlepower, provided a visibility of 40 miles in good weather. Daytime visibility was much less difficult.

In 1926, pilots could only receive weather information, and details about other planes in the air, while on the ground, before takeoff. If conditions changed while flying, no one on the ground could warn them. A pilot had no way of communicating with anyone on the ground.

By April, 1927 an experimental ground-to-air radiotelephone system began operating with a range up to 50 miles. Soon after, a ground based transmitter located on the transcontinental airway successfully communicated with an airmail plane 150 miles away. The range limitation was not as with modern VHF Avionics; line of sight. It was limited by power, sensitivity, & weather. LF (low frequency) AM radio was seriously impacted by electrical interference from storms.

By mid 1927, 4,121 miles of airways were equipped with lights on towers. By 1933, 1,500 beacons were spaced along an assortment of airways that covered a total of 18,000 miles. Some towers were located on airports, but many were in open country; much like the modern day VOR OMNI Range transmitters, with spacing again by line of sight for visibility. These towers were not decommissioned until the mid 1950s. A few towers still stand on airports; abandoned.
Elaborate as the visual beacon established airway system was, it left much to be desired. Its greatest disadvantage was that it relied on visual contact. At night the beacons were visible from 40 miles only with 40 miles visibility; & not while flying in clouds. In the daytime the same was true. Flight above a cloud deck lower surface, day or night was neither safe nor practical. There was no way to know when they should descend if they tried to fly in what would later be called IFR.

Flying from one visual beacon to another required identification of each tower, & flight charts. The Morse code was added to beacons to permit positive identification of each beacon. Changing routes required knowledge of the location of each intersecting airway, & the angle of turn required to follow another airway. This information was provided first on notes provided; later on charts

4.5 Aero Navigation System No. 5; LOP (Line of Position) by Solar Sighting:

4.5.1 Background:

The solar LOP certainly predated Aero Navigation. In Dec. 1837, Capt Thomas Sumner, an American ship's captain, discovered the consistency of the elevation of heavenly bodies above the horizon, & realized the potential usefulness of that information for a LOP. His discovery was considered to be the greatest accomplishment in Navigation at that time in history. It was soon found to be especially useful in the polar regions, where the magnetic compass was ineffective.

The earliest celestial Navigation used sticks & strings as discussed in Aero Nav system 5.

A LOP may be a straight line, segment of a circle or an irregular line; the latter typically being a shoreline. An LOP could even be a railroad or river that winds its way to the destination.

A primitive predecessor of the AstroCompass (sometimes called a Sun Compass), was developed to determine the bearing & altitude (elevation) of the sun. The AstroCompass is still sold & used for that purpose. AstroCompass is normally written as 1 word. It is useful in Aero Navigation with aircraft large enough to allow an "Astrodome". Astrodomes are also useful with a Sextant; for Celestial Navigation. It is possible to obtain a fix by use of an AstroCompass, but that requires considerable time, & lengthy computations. An AstroCompass can provide each of the following (individually): latitude, longitude, sun "altitude", time, position, direction, or LOP. The unknowns that may be established depend on what is known.

It is likely that early sailors used primitive LOPs based on land features when visible, such as mountain tops; actually lines of sight. This would require a relative bearing; such as 45° off the port side bow. Wait "half a day" for it to be off the stern & repeat the sighting. A LOP is the initial object of most Aero Nav systems. A LOP is actually broader than the solar, or even celestial line. it is a line along the surface of the earth on which the plane is known to be following or crossing at a specific time The LOP is vital to Aero Navigation, & can be obtained by use of any of a variety of Aero Navigation systems. Multiple LOPs provide a fix, which is the primary object of any nav aid used for Aero Nav. A single LOP may be all that is required, such as in homing in on a beacon to reach that radio frequency transmitter.

4.5.1.1 Time System as Applied to Celestial Navigation

Early in the history of the U.S. LMT (local mean time) was used. Noon was when the sun was at its max altitude for that longitude & that day of the year. A few miles West, noon occurred a little later. The sun was, of course, rarely if ever precisely at the observer’s Zenith, because the solar declination rarely coincided with the observer’s latitude. Before time was standardized, scheduling of trains was difficult. Train management demanded a more standardized time, & based schedules on a standard time.

Exactly how is “time” defined? Because of leap year & other very small errors there are actually approximately 365.25 days per year. Time is obviously based on 24 hours per day. In celestial Aero Navigation, rotation of the earth, time, hour angle, & longitude are all inter-related. Hour angle relates to time reference; GMT. The time of transit is based on the longitude since time is referenced to Greenwich, England; as is longitude. The upper transit time occurs at 12:00 noon each day, but only at the mean meridian of that time zone. As the sun passes the observers position (meridian) it is said to have passed at the “time of transit”, at the upper transit time. “Mean solar time” is based on the average apparent solar time, a fictitious sun. “Mean solar time” differs only slightly from “mean day time”; never more than 1 minute in a day. This difference is, however, cumulative, so they do differ as much as 15 minutes throughout the year.

For Aero Navigation purposes the military, NWS (National Weather Service) & FAA prefer to set watches or clocks at ZULU. EST, CST, MST, & PST (or daylight versions of same) still leave much to be desired. One reason is that the NWS reports weather in GMT to avoid confusion. Flying 1,000 miles East or West, it is important that the forecast ceilings, or severe thunderstorms at destination be given in an unambiguous time reporting system; ZULU.

The dual display, 5 function dual digital display Heathkit clock served the author & his wife very well by offering simultaneous ZULU & local standard time displays; or ZULU, along with elapsed time from take-off, or a 24 minute count-up in seconds & minutes for instrument approaches; without interrupting the other display counts. Having bold LCD digital displays instead of the less visible LCDs reduced the risk of confusion over time in the air, as well as NWS or controller reports. A wrist watch served well for the less critical local time. He highly recommends having a 2 stop function clock at a minimum (1 for approaches & 1 for total flight time) & both ZULU & local CST / CDT.

4.5.1.2 Curious Bits of Info re Astronomy:

4.5.1.2.1 An imaginary line across the points of a crescent moon align with a direction of roughly South when in the Northern hemisphere.

4.5.1.2.2 As mentioned elsewhere, the North Star, Polaris, is always roughly directly North of the observer; within 3/4°. It circles the pole. When Polaris is directly beyond the true North pole of the celestial sphere it is effectively due North of the observer. Exactly 6 hours later it will be directly to the right (3/4°), & another 6 hours later, 3/4° below the true North pole (thud directly at true North), & another 6 hours later (18 hours from the initial position) it will be 3/4° left of the true North pole. For simple alignment to determine true North, at 2 times per day Polaris will appear directly North of the observer, & for most purposes it amybeconsidered due North at all times.

4.5.1.2.3 The reader may have wondered why the latest sunrise in the year is nearly 1 week after the Winter Solstice?

The sun traces-out a figure 8 pattern. Observing from the Northern hemisphere, this "analemma" has a small top loop, and a large lower loop since the earth moves slowest in its orbit around the sun between spring-summer-fall, than in the fall-winter-spring period when it is approaching perihelion on the winter solstice and moving the fastest along its orbit.

The bottom of the winter loop analemma indicates the position of the sun at the winter solstice when it arrives at its highest Northern position at a declination of +23.4 degrees. The analemma only appears perpendicular to the horizon when observed while at the equator. Only for observers along the equator will the latest sunrise (and the earliest sunset) always occur on exactly the Winter Solstice. Observers at other latitudes will note that the analemma is tilted because of the tilt of the axis of the earth.

4.5.2 Theory:

4.5.2.1 The Concept of LOPs

The theory of LOPs is simply to establish a relative bearing from the plane, convert to true bearing, & plot on a Sectional or similar chart. In the case of solar or other celestial bodies it involves elevation (altitude) as well. Although this Aero Nav system is devoted to solar LOPs, an LOP can be determined from any identifiable landmark or celestial body that has a known location. The AstroCompass is the primary instrument for solar LOPs. Multiple LOPs are required to establish a fix, which is normally the goal. Determining the orientation of true North is another, major capability of the AstroCompass.

4.5.2.2 The Relationship between the Earth, Solar Sphere & Aero Navigator.

The sun's rays strike the surface of the earth at any given point, at an angle based on 2 factors: the day of the year, & the time of day. The apparent location of the sun to an Aero Navigator depends on the latitude & longitude of the position of the plane, the day of the year, & the time of day. Fig 28 & 29 illustrate the earth & solar system in terms of the various relationships, terms, orientations & values. These angles can be determined by a series of actions. Fig 28 shows the earth as seen from above the North pole. It is obvious that even though the declination of each heavenly body is fixed (except for planets), the altitude appears to change as the body moves West relative to the Aero Navigator. Since the AstroCompass & sextant either measure, or are set to the elevation, the time of day impacts the altitude reading.

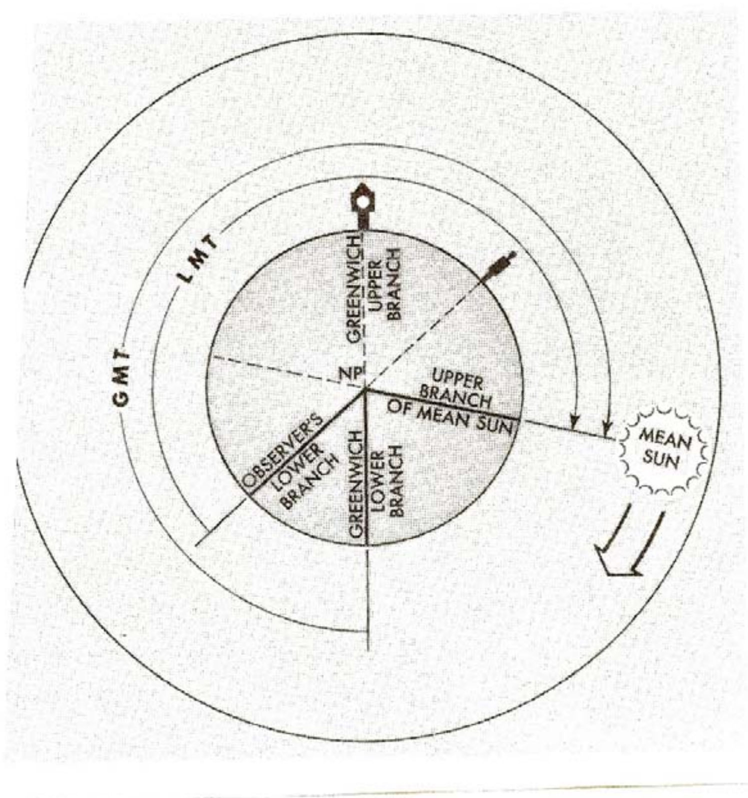


Fig 28: Measuring Greenwich Time

The North to South & reverse movement of the sun (relative to the earth) causes the seasonal weather changes. The Equation of Time graph (plot of time vs. declination) covers a full year, & resembles a “climbing sine wave” rather than a figure 8, as one might expect. The declination of the sun is zero degrees at the 2 equinoxes; Mar 21st & Sept 21st. The N & S extremes are 23.5° & occur on June 21st (summer solstice) & Dec 21st. (winter solstice). The moon may also be used for celestial navigation. It cycles through its full declination period monthly; from + 18° to - 18° & back. Its equation of time graph then covers only 1 month in time. This is also true of the signs of the zodiac. Since the AstroCompass is used to follow the sun's path, solar time should be used. Solar time differs from clock time by a few minutes through 6 months & about 1 hour earlier when daylight savings time is in effect.

The progress of the sun "around" the earth is given in GHA corresponding with longitude. Since the sun appears to rise in the East, & move to the West, the sun GHA increases during the day. The "time of day" is the primary contributor to GHA, but the day of the year is also a factor. An indication of this effect is the comparison of May 1 with May 30 during 1 specific year is given in the upper table of Fig 29. The longitude component of the altitude of the sun from the Aero Navigator's position is only 2 arc minutes. But declination changed nearly 7°. Since declination is equivalent to latitude, & the 7° component is along a great circle, the 7° error would, if not taken it account, amount to an error of approximately 400 miles.

Engineers tend to think of the sun position as relative or true bearing & elevation above the horizon. Astronomers & celestial navigators call angle above the horizon "altitude", & refer to GHA. Another subtlety that confuses newcomers to celestial navigation is the fact that often several terms are used to describe the same item. You might say they are "apparently unrelated" synonyms.

G = Greenwich England meridian; ZULU, & is shown at bottom of the illustration of Fig 28.

The upper table of Fig 29 data was taken from an obsolete official Air Almanac. The lower table gives data for a randomly selected year; for the first day of Jan. This small table includes only 3 of the 5 planets, plus the sun that may be used to obtain a celestial LOP or fix. Fifty seven stars are also used for celestial navigation. Stars & planets used for celestial navigation were selected on the basis of magnitude (brightness) & location on the celestial sphere. Sky charts associate stars with constellations, which were assigned as an aid to locating navigation reference stars.

Representative Celestial Data						An Air Almanac must include the year, month, & day of intended use.
Impact of 1 month on sun & Moon data						
Month for both lines of data: May (year N/A for this; critical to actual Aero Navigation)						
Time for both lines of data: 12 noon GCT (Greenwich Central Time)						
Date	Sun		Moon		Air Almanac actually includes other planets & stars, also. It also included Moon latitude & other data.	
	GHA	Declination	GHA	Declination		
1	0° 43'	N 14° 53'	33° 21'	S 1° 27'		
30	0° 41'	N 21° 41'	39° 49'	N 6° 14'		

Some Examples of Air Almanac Information								
Month & Date: January, 1, XX. (Year is irrelevant for example; critical for Aero Navigation)								
GCT	Sun		Mars		Saturn		Moon	
	GHA	Declination	GHA	Declination	GHA	Declination	GHA	Declination
2040	129° 08	S 23° 01'	160° 02'	S 22° 21	345° 25'	N 19° 36	195° 01	S 9° 02'
2050	131° 37'	S 23° 01'	162° 32'	S 22° 21	347° 55'	N 19° 36	197° 26'	S 9° 04'
2100	134° 07	S 23° 01'	165° 03'	S 22° 22	350° 26'	N 19° 36	199° 51'	S 9° 06'

Fig 29: Representative Celestial Data:

Note that for comparative purposes the year is of no concern, although celestial navigation requires an Air Almanac with the exact current day, month, & year for a fix; along with time to the nearest second. Because of the subtle changes & imperfect time relationships the air almanac for Jan 1 2009 is not acceptable for Aero Navigation on Jan 1 2010. Note that a 1 second timing error results in a 1/4 NM LOP error.

The safest, but no longer the most practical way to solve a celestial navigation problem is to use the air almanac along with the HO 214 "sight reduction" tables which provide pertinent info, including declination. Because spherical trig is quite complex, sight reduction tables were developed. They are simply pre-computed solutions to celestial navigation problems using spherical trigonometry. Note that HO 214 dates back to WWII, while HO 229 & 249 are more recent editions of the same. The "sight reduction" tables are, however, for long distance flight, inconvenient, if only because they are so very bulky. Just a single volume of the earlier H.O. 214 tables covers only 10° of latitude, so a full set is large & heavy. The later H.O. 249 sight reduction tables are somewhat smaller, but still bulky. Interpolation tables are included in each volume of "sight reduction" tables to facilitate accurate readings.

A total of 57 stars, the sun & moon, & 4 other planets are charted for celestial navigation in the air almanac.

4.5.2.3 Technological Advances

AstroCompass & sextant advances were made over many decades, but most individual developments were moderate.

Modern technology has again surpassed the old inconvenient Air Almanac. Several electronic versions are on the market. A set of air almanacs is quite costly, & considering the fact that instruments such as the Starpilot include a data base that lasts until the year 2100, it seems to be a good value at $400; vs. frequent air atlas replacements. Both the Starpilot & the air almanac may be used to support either an AstroCompass or a sextant. A full set of sight reduction tables is also available as a software package, if an Aero Navigator prefers to use his own computer. Again, electronic devices do fail; even the U.S. Navy relies on celestial navigation as a daily back-up for their GPS systems.

4.5.3 Accuracy & Efficiency:

The AstroCompass is capable of providing several types of information. It is named for its primary purpose; compass. It is thus used for determining the direction to true North. It is very accurate in this function. In flight use of an AstroCompass in turbulent air may produce an error as large as + / - 2°.

The AstroCompass was initially designed for obtaining solar LOPs. The altitude or elevation is set using a rather crude "gun sight", so only has a resolution of 1°. By estimating, the accuracy might approximate 1/2°. The latitude is set using a vernier, so is more accurate. The elevation component of the AstroCompass accuracy is then 1/2° at best. Depending on relative altitude the position error could be 30 NM.

Solar sighting is efficient in that even though it is limited in capability, Aero Nav using the AstroCompass is not limited to following airways. Flight may be in any desired direction, including directly from departure airport to destination airport free of any deviations; thus both distance & time of flight are as short as possible.

4.5.4 Application:

4.5.4.1 LOP & The Astrocompass

An AstroCompass has 4 independent axes, sometimes written with upper case A & C. An AstroCompass can be used to "shoot" any identifiable star or planet, but only the sun casts a shadow on the sight plates. Other celestial bodies must be sighted by use of its "gun sight-like" feature. The sextant can also be used to shoot LOPs. In fact, the norm is to shoot 3 LOPs with a sextant for a celestial fix. The sextant is discussed below. The sextant is much more sophisticated & precise than the astrocompass. A sextant is sighted at any known, documented celestial body (usually a star) & automatically averages its altitude value over a very brief period of time. See note under "AstroCompass Operation for Sun LOP Determination & Computation" below for star vs. heavenly bodies with larger subtended angles.

The 3rd dimension certainly complicates the solar LOP & also celestial navigation in general. A 2 dimensional simplification illustrates how it works. A sailor could use a simple theodolite, an AstroCompass, or a magnetic compass with a makeshift sight attached to establish his position. He could locate 2 or 3 landmarks & determine their relative or true bearing from the boat. If he can identify a distant mountain peak as being due North of his position, he can draw a line straight South of the mountain on a chart. He then knows that he is located at some unknown point along that very long line; conceivably 1 mile, or even 60 miles from the mountain. If he then measures the true bearing to or from a bridge & finds that he is due West of the bridge, he can draw a line directly East from the bridge. The intersection of these 2 LOPs establishes an exact position. Just how exact depends on the accuracy of the angular readings; the LOPs.

Pre-computation on the ground, or even in flight before reaching the point that a solar sighting should be taken would expedite the process, & prevent falling behind the plane. This is especially important in the case of Aero Navigation in a high speed aircraft.

The Aero Navigator has at his disposal a wide variety of methods of obtaining a LOP. Limited celestial navigation can even be accomplished by use of crude sticks and scraps of paper; or strings.

A solar LOP is most often obtained by use of an AstroCompass. Celestial LOPs can be obtained by use of a sextant or an AstroCompass.

A LOP is not a fix, so the aircraft could conceivably be precisely on the desired LOP & actually be hundreds of miles from the intended place on the earth. The ideal Aero Navigation system provides a fix; or even better, a continuously updated position; not incrementally updated as the plane cruises along. That is possible with some of the more modern Aero Nav systems, but not with affordable celestial systems. The only way that a single LOP will provide all that is necessary for a fix is if the LOP inherently intersects an identifiable object. An example might be an island or coastline, which, combined with the LOP, would constitute a fix. A mountain or similar distinct easily identifiable terrain feature can provide a LOP if the relative or true bearing can be measured; even if only by sighting down a wing skin seam line, if the angle is known.

An Aero Navigator could conceivably follow a solar LOP that will cross an island. If the plane drifts off course far enough that the island is beyond the horizon, or the distance off course exceeds the visibility at flight altitude, the island cannot be seen, & a ditching in open sea is likely. To preclude that disastrous event, the Aero Navigator must find a way to "follow" or intercept a LOP directly to the island.

Ideally an LOP should lie along (or be near & parallel with) the intended track, if drift is the most important issue. Conversely, an LOP perpendicular to the track would be most useful in determining landfall if that is the greatest concern. In that case the Aero Navigator must determine whether to turn left or right upon reaching that LOP. A deliberate offset may be the best tactic in that case.

A sun line (LOP) affords a good way to determine the proximity of the plane to the intended track, or if at a relative bearing that is 90° from the above, for progress along a track. Continuous monitoring of any portion of the positional info is

inconvenient by use of an AstroCompass. Each LOP must be computed & "sighted" when required. If the LOP happens to coincide with the intended track, staying on course would be greatly simplified, except that fuel supply might be a concern if an undetected GS decrease occurs. If the LOP directly crosses the course line, progress along the course is easy. If the LOP crosses the track line at any other angle the information gleaned from it must be treated in whatever manner seems appropriate.

4.5.4.2 The Relationship between the Aero Navigator & Celestial Bodies

The solar LOP obviously involves a daytime observation. Limitation of a single body also means a single relative or true bearing. The value & even usefulness of the solar LOP depends on the time of day as well as the direction of flight. More importantly, a fix is impractical.

The addition of stars & planets significantly extends the usefulness of the AstroCompass, but limits sightings largely to night time.

A fix is possible at night with an AstroCompass, which is well suited for stellar observations.

The Aero Navigator (observer), in Fig 28, is shown at 45° W longitude; 45° CCW from the sun. For the purpose of "shooting" a sun LOP, the only missing information is the Aero Navigator's latitude. He can obtain his latitude using solar sighting with the AstroCompass at local noon. A running fix is possible with limited accuracy using solar sightings.

The lower table of Fig 29, at 2040 GCT, indicates the sun GHA of 129, which coincides with the GHA of Fig 27. The lower table of Fig 29 shows the sun declination (latitude) to be 23° 1' S, the total difference in latitude is then 53° 1'.

Aero Navigation position is 30° N latitude & 156° E longitude; East of Greenwich.
Sun altitude-latitude is 23° 1', & GHA is 129.

Assume a sun LOP is desired for January 1 & the above conditions. LHA (local hour angle) is determined as follows:

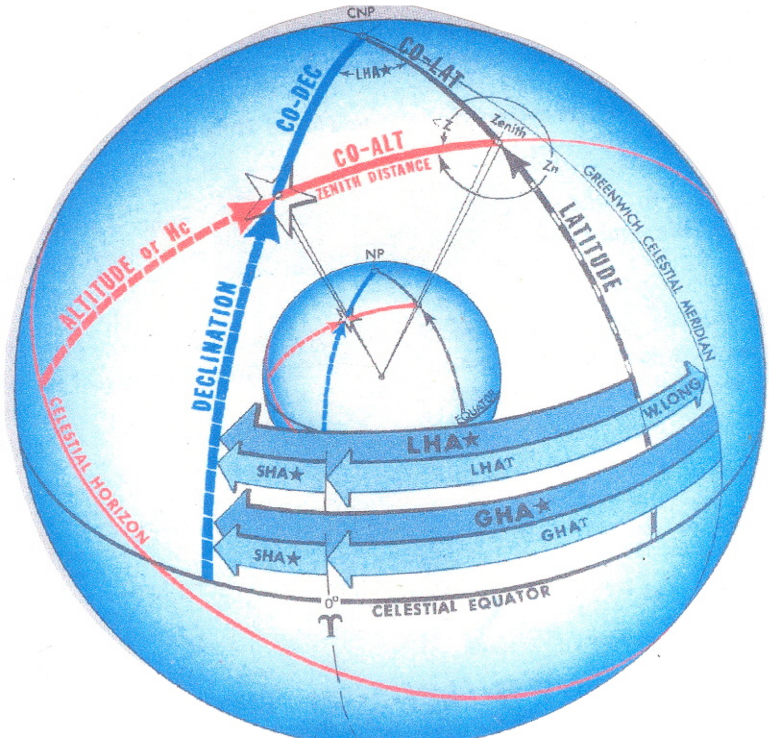


Fig 30 Celestial Sphere & The Earth

Longitude is given up to 180° in East or West longitude, but sun GHA is given up to 360°.

LHA is the angular distance between the Aero Navigator's position & the sun, or 360 - 129 - 156 East = 75° East measuring along parallels of latitude. Unless both the Aero Navigator & sun are on the equator, the AstroComass will not "see" 90° - 75° = 15°. If the Aero Navigator is near the North Pole, the sun will appear much lower; at a lower altitude. The further South the sun is, the larger the angle from the vertical will be, if the Aero Navigator is in the Northern hemisphere.

Fig 30 illustrates the celestial sphere & the earth together. Most terms are illustrated. The point in space directly above the Aero Navigator is called the zenith. This illustrates the significant effect that declination of sun, & the latitude of the Aero Navigator position have on the observed sun altitude. The Aero Navigator latitude is well above the equator in this illustration while the sun latitude is below it.

An AstroCompass is sometimes called a sun compass. A schematic & 2 photos are shown in Fig 31 to 33. Given knowledge of position, & the air almanac, it can provide the exact orientation; thus true North, with moderate effort & care. In polar regions true North is not otherwise easily obtainable.

The AstroCompass also affords a means of determining the "altitude" & the azimuth of the sun at any time, or from any location. The process is, however, more complex than just pointing an AstroCompass at the sun.

The AstroCompass is illustrated schematically with annotated parts and controls in Fig 31. It consists of:
A base plate with independently adjustable legs for leveling.
A 2 axis level indicator.
A calibrated 360° azimuth circle.
Both North & South hour circles calibrated in degrees.
An equatorial drum with calibrated course latitude scale & a fine scale plus a calibrated micrometer dividing scale.
A visual sight designed for alignment with high or low intensity bodies; sun & stars.

Technology again offers more advanced features which are not represented in this Aero Nav system. Fig 32 & 33 are photos of different views of 2 existing designs to clarify the schematic. There are dozens of different makes and models of the Astrocompass.

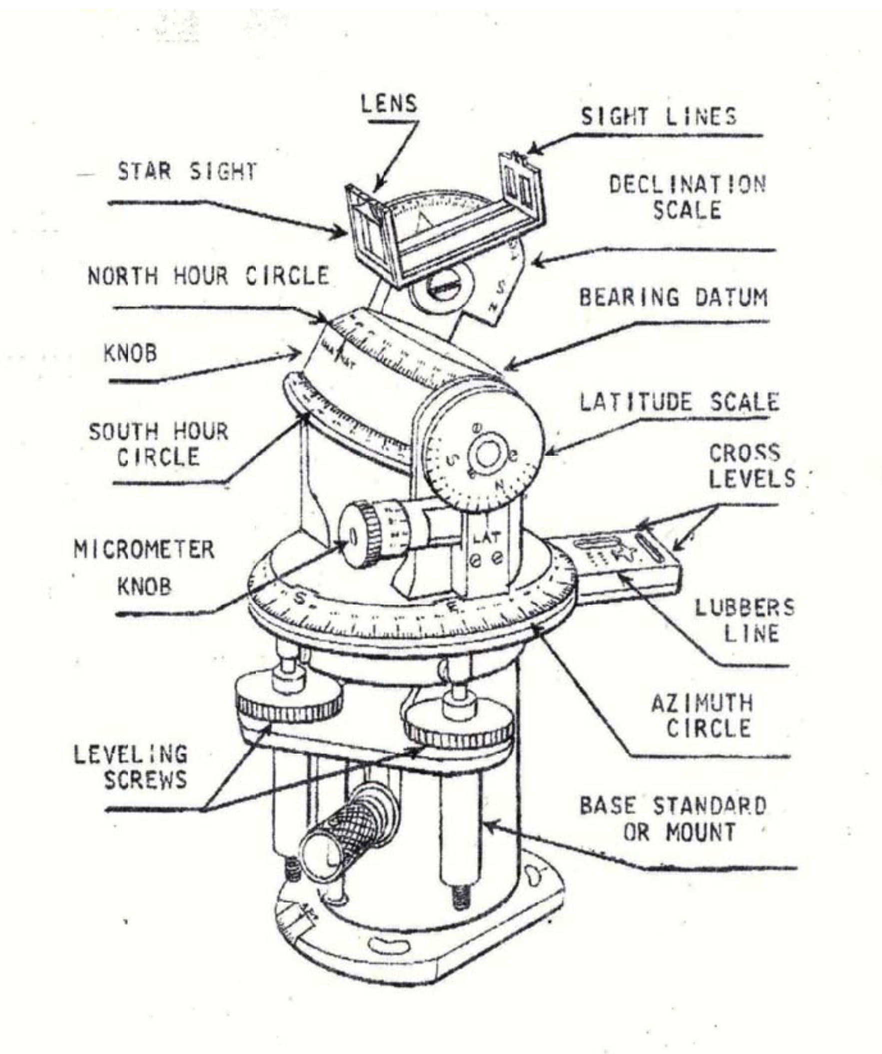


Fig 31 - Astrocompass Schematic

The procedure for finding true North with an AstroCompass is:
- Mount in plane that is flying a steady constant heading per the preflight.
- Level the base.
- Rotate the azimuth circle until it is set to the anticipated true North.
- Tilt the equatorial drum to the best known local latitude.
- Set the hour angle to the appropriate local hour angle.
- Set the declination angle to the declination of the observed celestial body.
- Rotate the lower azimuth circle to align the celestial body properly in the sight.
- Read the azimuth circle to establish true direction of true North; & aircraft true heading.
- Next adjust the 2 "bubble levels" using the appropriate "leveling screws". Each screw lifts only one axis & level, so interaction is avoided.
- Then orient the equatorial axis by setting the best known "latitude" on the "latitude scale" using the "micrometer knob".
- The "latitude reference line" & micrometer index line serve as references. Note that latitude has both fine coarse scales; coarse on the vertical disc gives 10s, while the vernier - micrometer knob gives the unity values. If the disc index shows 4 & the micrometer knob shows 3, the latitude is set to 43°. The latitude can be estimated to only a few tenths of a degree. The hour scale should move 4° per minute (earth rotates 15° per hour).

If flying in the Southern hemisphere, set the LHA (local hour angle) on the lower canted (latitude) "hour circle" scale. When flying in the Northern hemisphere, set the LHA (local hour angle) on the upper canted "hour circle" scale.

Next rotate the "sight assembly" to the anticipated "declination angle"; or if unknown, until the shadow of the forward vertical sight bar, especially the horizontal pointed protrusions, is centered on the translucent screen. Both vertical &

horizontal alignment are critical, since sun altitude & azimuth are both important. Adjust the other previously set values, if necessary, to optimize alignment of the shadow. Note: the astrocompass can be used to sight stars which are actually a "point source". A point source is too small in diameter to measure by any means, & their light is totally collimated. The front sight for point sources is much like the rear sight on a firearm. The rear sight on the astrocompass consists of a lens with reticle. Sighting through the lens the star must be centered between the front blades & aligned with the reticle.

Read all scales to determine how they impact aircraft position (LOP).

Note projected aircraft position at the exact time of the final observation. As always in Aero Navigation the time of the sighting, not of reading the scales, is the time of the LOP. If the final adjustment that established the observation was taken at 1100 Zulu, then the assumed GS must be applied to the last fix to determine the most probable aircraft position at 1100 Zulu.

Plot the position of the LOP on a Navigation chart & determine the most probable aircraft position at 1100 Zulu.

Repeat the entire process as often as necessary during the flight to assure safe arrival at the destination.

It is always beneficial to perform as many computations as practical before leaving the ground; during the preflight. The Aero Navigator should first select a few uniformly spaced intermediate points along the route, & document latitude & longitude, as well as the ETA for each intermediate point, as well as for the destination. These intermediate points should be used during the flight to reduce the workload, although they must be updated in flight if GS or other changes are noted. It is most important that minor adjustments of heading - course be made as the flight progresses to reduce the risk of requiring major heading change at the last minute. Most important, if all Aero Navigation systems fail during the flight, he will be in a better position to continue using only DR. If the Aero Navigator is "just along for the ride" because his GPS takes all the work out of Aero Navigation, & the GPS fails, he could have great difficulty establishing his position & ETA. It is his responsibility to follow the progress of the plane continuously. Failure to do so could result in a loss of all.

He can repeat the sightings periodically to establish a series of LOPs & adjust heading if justified.

He should mount the AstroCompass in the plane, level it, & orient it so that it points to true North with the plane flying a steady heading.

He must then adjust the AstroCompass for the longitude of the first of these intermediate points.

Then he must adjust the declination angle for the day & season, per the air almanac. The declination is the tilt of the earth relative to the sun. It varies with the seasons. The declination is 0° at the equinoxes, which are March 21st and September 21st. The extremes of the declination are the solstices; 23.5° N on June 21st is and 23.5° S on December 21st.

In Fig 31 the declination scale on the top of the AstroCompass extends from + to minus 65°. Why 65° when declination should not exceed 23.5° because the plane may be far from the equator, so latitude & declination may be additive.

If the Aero Navigator can develop another LOP; hopefully crossing at near 90°, it will result in a fix; a specific small point. The second LOP might be from the same Aero Navigation system; or any other. The time of the LOP measurement must be noted. That time must be advanced, by the factor [delta time x best known GS], so the time of each LOP is shown at the same time.

For accurate time measurement, a clock or watch with "hack" capability, reading to 1 second, & set to WWV; NITS (Atomic clock radio transmission time signal; National Institute of Standards & Technology, in Colorado Springs, Colorado is preferred.) In the case of lateral displacement error, 4 seconds = 1 arc minute & results in a 1 nautical mile error. WWV time, like ZULU, does not recognize Daylight Savings Time.

The Impact of Time on Celestial Navigation:

The hour angle is critical to celestial navigation. The rotation of the Earth is summarized below:

360° of longitude per 24 hours,
15° of longitude per hour,

1° of longitude per 4 minutes of time,
15 minutes of longitude per minute of time,
1 arc min. of rotation will result from 4 seconds of rotation time; so a 4 second time error will result in a 1 NM error.
15 arc seconds per second of time,
1 arc second of in longitude will result from 4 seconds of time.
1/4 arc second of longitude per second of time.

How does he know what these values should be, & how does he adjust the AstroCompass?

Aircraft electrical systems do fail, however infrequently. Avionics also very rarely do fail. Even less often, the Feds may either shut down, or encode ground & satellite based navigation aids for security reasons, in cases like 9-11, or all-out war. See Note 1. These nav aids would then not be usable by any Aero Navigator, except for the military. Barring the availability, in that instance, of more modern Aero Navigation systems, a solar or other celestial LOP may be the only way to assure a proper landfall.

Note 1: Immediately after 9-11 all aircraft except military were required to land at first opportunity. No take offs were allowed. All remained grounded for a period of time. The author was grounded for over 1 week, & limited severely for several months. Only flights under IFR flight plans were permitted; & only directly between 2 points. This restriction lasted for several months. The greatest concern then was that the return flight plan was required to be filed while on the ground. If that flight plan had not been approved it may have resulted in inconvenient ground travel. This was certainly not the norm. All pilots were advised to respond in a specified manner if they found a fighter jet off their wing. VFR flight was not allowed for quite some time.

All of these inconveniences were, of course, insignificant in view of the national disaster & risk. Although very fast & serious response by the executive branch, & all levels of police & military did keep the country free of any future attacks, Genav Aero Navigators & pilots must be prepared for a sudden mandated premature landing in the event of another attack by irrational, misguided, cowardly terrorists. As of 2010 the proposed White House response is reported to be a disaster to all of aviation & marine navigation.

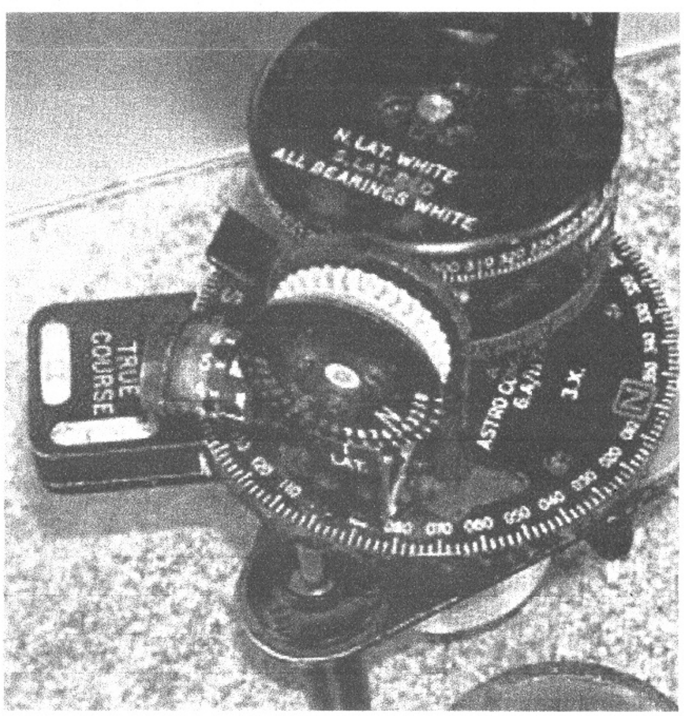


Fig 32: - Astrocompass Sun & Star Sight

4.5.4.3 Determining Latitude from Meridian Altitude

A solar sight taken by an AstroCompass can determine the altitude of a celestial body directly when it is on the observer's meridian. This procedure is employed *to* determine the observer's latitude, and it is one of the simplest problems in celestial navigation. Its solution is derived from the fact that when a body is on the observer's meridian, its local hour angle is zero, hence the astronomical triangle is simply a straight line.

The procedure for determining latitude by meridian altitude is:
a. Sight on the celestial body to determine its altitude.
b. Subtract true altitude (Ho) from 90° to determine zenith distance (Zd) by .

90° - Ho = Zd

c. Determine the bearing of the observer's zenith from the celestial body (North or South) and name zenith distance accordingly. Assume , for example, that the zenith is labeled North (of the celestial body). The zenith distance, then, is labeled North. If the zenith were South of the celestial body, the zenith distance would be called South.
d. Combine zenith distance and declination to obtain observer's latitude. If values have same label (N or S), add them together and give the resulting latitude their label. If values have opposite labels, subtract smaller from larger to obtain their difference which will take the label of the larger value and will represent the observer's latitude.

Zd +/- dec. = Latitude

Case 1:
If observer Zenith is North of a star:
Declination = 12° 00' N
Hs of star = 55° 00'
Refraction = 0'
Ho = 55° 00'
90° 00' - Ho = Zd = 35° 00' N
Zd + declination (12°) = Latitude
35° + 12° = 47° 00' N

Case 2:
If observer Zenith is South of a star:
Declination = 12° 00' N
Hs of star = 60°00'
Refraction = 0'
Ho = 60° 00'
90° 00' - Ho = Zd = 30° 00' S
Declination - Zd = Latitude
43° N - 30 S = 13° 00' N

The term "running down a sun line" describes a procedure that is particularly useful in reaching a small destination such as an island in a large ocean. Missing a small island might result in ditching at sea after fuel exhaustion.

If an aircraft is over a large ocean while heading for a small island, few possibilities are available.

Conditions VFR, daytime. Radio nav aids are non-operational, or were turned off for reasons of national security because of misguided inhumane terrorists.

4.5.4.4 Running Down a Sunline (an example of another use for the AstroCompass)

The Aero Navigator can use DR to establish his approximate position for 2:20, having flown for 1,000 miles, having used some Nav Aids before the catastrophic failure. Assume his ETA to destination is 1 hour.

Assume a course of 209°-G.S & a GS of 180 knots.

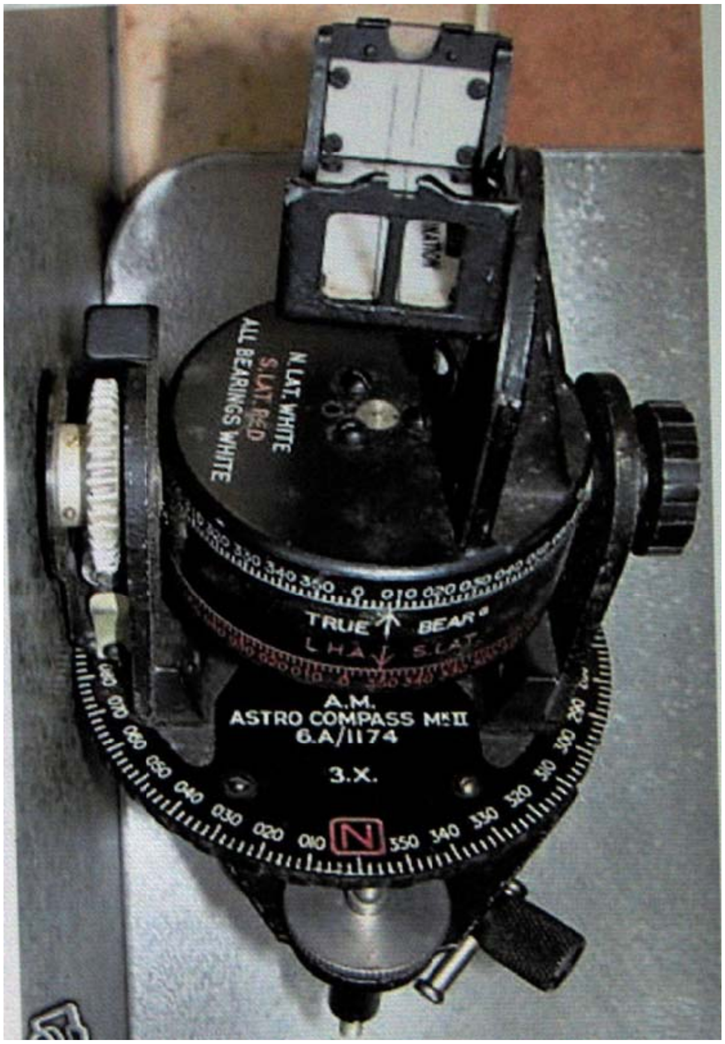


Fig 33: - Astrocompass Sun & Star Sight

Assume a sun line & DR position & advances the time of the LOP to the planned alter point, after estimating possible drift errors both left & right of intended course. He alters his heading so that he will almost certainly fly past the destination on one side of course. His new heading is 223°, & estimated distance is 128 NM. He should pass to the right of the island.

Assuming his GS remains at 180 knots, he should pass the island in 43 minutes (128 NM / 180 knots).

He should pass abeam of the destination at 3:03 pm local time. He must, of course, use celestial time.

He should shoot a sun line using his AstroCompass in advance of that time to assure that his computations are correct. At 2:40 his sun line shows a passage at 3:00.

He holds his heading (223° TH). He must not pass on the wrong side of the island; he'd turn the wrong way & fly off until he realizes his mistake or runs out of fuel.

He computes that the sun line should be 148° at his new ETA as the sun line passes over the destination at his latest ETA; 3:00 pm local. He makes one more alter to a TH of 168° (reciprocal of 148°) so that he will "run down the sun line", and thus fly over his destination.

A simple solution to what might have been a catastrophic situation under the adverse conditions described in this example.

Sun LOP-Rev Example

HO 214 or HO 249 Sight Reduction Tables & Air Almanac Tables were used.
All were for a specific date, but any date works as long as all dates agree.

Key to Symbols: Flight at 5,000'

a	=Intercept Alttiude
Astronomical Triangle	= Spherical Trig tabular listing; found in HO 214 or later tables.
Az	= Azimuth; angle at the zenith from observer's meridian to the vetical circle that passes through a celestial body
Declination	= Angle of the sun or other celestial body above (N) or below (S) the equator.
Δd	= difference between consecutive Hc values
DR lat or lon	= Dead reckoning Position
GAST	= Greenwich Aparent Siderial Time
GCT	= Greenwich Civil Time
GHA	= Greenwich Hour Angle
GMT = UT	= Greenwich Civil Time
H = h	= Body Atitude
H.O.	= Heading for HO 214 or late Sight Reduction Tables
Hc	= Computed Alttiude from DR Position
Ho	= True Alttiude
Hs	= Observed Alttiude
IC	= Instrument Correction
LHA	= Local Hour Angle
UT = GMT	= Greenwich Civil Time
Zn	= True Azimuth; measured from true north to vertical circle passing through celestial body

Problem Description & Conditions:

May 1, 20xx, GCT = 22 hours 32 min. 10 sec., Hs sun 16° 12',
I.C. = -9', DR latitude 31° 45' N, DR longitude 120° 50' E.

Sun:

GCT	22 hours	32 min.	10 sec
GHA	22 hours	32 min.	= 158° 14'
+ for 02 min 10 sec			= 33'
		GHA	= 158° 47'
DR longitude	121°	13'	= 121° 13
			280° 00'
Subtract above from			360°
LHA			= 80° E
DR latitude			= 32° N
Declination			= 15° 02' N
Enter HO 214 Sight Reduction Tables with:			LHA = 80° E
			Lat. = 32° N
			Dec.= 15° N
Hs =			16° 12'
IC =			'-9'
Ho =			16° 03'
Hc =			16° 03'
a =			11.4 ' away
Δd =			0.50 x 2' = 1.0'
H			16° 13.4
Δd correction			+1.0'
Hc = sun alttiude from DR position.			16° 14.4'
Az =			N 82.2° E

Δd = difference between 2 Hc values.

Fig 34: Sun LOP Example

4.5.4.5 Sun LOP Example

Fig 34 provides a complete analysis of one case.

4.6 Aero Navigation System No. 6: Celestial Aero Navigation

4.6.1 Background:

At any given time the apparent position of stars in the sky is predictable. As the earth rotates the stars appear to rotate, but their relationship at any given time, & from any point on the earth, may be predicted by use of an air almanac. As such, they can be used to establish a position on the face of the earth by a reverse analysis using the same almanac & angular measurements taken by an instrument. Stars are so far away (essentially an infinite distance**,** & fixed in space) that neither the rotation nor the orbit of the earth upset the relationship. It is thus practical to use the location of stars in the sky to establish the 2 dimensional position of a plane above the earth; celestial navigation is thus quite practical.

As stated in the discussion of the AstroCompass, Capt Thomas Sumner, an American ship's captain, discovered the consistency of the elevation of heavenly bodies above the horizon, & realized the potential usefulness of that information, in Dec. 1837; for a LOP.

The sextant, which is the primary instrument for celestial Navigation, dates back several centuries. Prior to that there were several "make-shift" devices that gave crude info for sea farers. The earliest was probably the finger width with outstretched arm; near 1.5°. Another of the simplest methods of measuring altitude was the "latitude hook" that was used by the Polynesians; one of the earliest known applications of celestial navigation. The "latitude hook" consisted of a piece of split bamboo with a loop at the top; its length was established as the desired distance between the horizon and the desired star to indicate that they had reached the desired latitude; having held the "latitude hook" at the correct distance. The Arabs developed a slightly better Navigation tool; a rectangle of wood cut to fit the distance from the horizon to the star. It used a knotted string, held in their teeth, assuring a consistent "arm's length".

The first evolution from the AstroCompass to the Sextant was the Octant. In 1757, a 120° angular scale turned the octant into the more practical sextant.

Modern sextants actually evolved from a 1660 Dutch invention of a reflecting cross staff instrument. Several British scientists independently developed the same instrument around 1731. Thomas Godfrey, an American, built one in 1730. A French mathematician invented the octant in 1732, & an Englishman developed a functioning octant in 1734.

The discussion in course 5 clarified the LOP. Two LOPs establish a fix, but each LOP is imperfect. Adding a 3rd LOP provides a triangle rather than a point, to improve accuracy.

Celestial tools & instruments became progressively more sophisticated; from crude devices to high precision instruments. Nautical sextants permit the navigator to view the actual horizon while aero sextants require a bubble to simulate the horizon since the earth horizon appears to drop as the plane climbs. Some nautical sextants use mirrors to permit simultaneous & coincident viewing of the horizon & the star of interest; much more practical than those without, it seems. Both types of sextants are also much more sophisticated & precise than the AstroCompass.

The ultimate in modernization, if the Aero Navigator is not a purist, is the all inclusive StarPilot calculator (or a similar instrument). It contains all of the air almanac data & more.

4.6.2 Theory:

The theory of celestial navigation is based on the fact that stars are fixed in space, while the earth has a very precise orbit & rotational rate. These facts assure an easily predictable apparent position in the sky at any time & location. If position is unknown, the same theory permits determination of the actual observer's position; a celestial fix.

The fact that planets, including the moon, also have reliable well known orbits, makes it possible to use planets as well as stars for celestial navigation.

Celestial navigation involves measuring angles at any given instant in time between celestial objects & a bubble that precisely simulates the horizon for the purpose of locating the position of a plane on the surface of the earth. The geographic position of the Aero Navigator is called the subpoint.

4.6.3 Accuracy & Efficiency:

The 3 star fix may be accomplished at any time, & at any point on the face of the earth, including flying in a perfectly straight line (ideally a Great circle) from departure airport to destination airport . Thus celestial Aero Navigation is efficient in that it can be used to maintain a straight line DR flight for the shortest time, lowest fuel consumption, & shortest distance.

4.6.3.1 Manual 3 Star Fix

A typical 3 star celestial fix is accurate to approximately 1 NM. Under ideal conditions an Aero Navigator can reduce the error to 0.5 miles, but under poor conditions the error may be several miles.

Since the LOP error will be 1 NM for each arc minute of altitude error, a valid altitude averaging system is essential. Each sighting consists of keeping the bubble & star aligned for several minutes. In view of air turbulence & Aero Nav movements the 2 will move, so constant adjustment is necessary. Automated averaging reduces the errors.

4.6.3.2 Sophisticated Fully Automated Multi Star Fix

There was a later innovation that revolutionized celestial navigation, but it was limited to users with very deep pockets. It is described in limited detail under Aero Nav system No. 22.

4.6.4 Application:

4.6.4.1 Selection of Suitable Stars

Celestial Navigation involves measuring the elevation (called altitude), of typically 3 stars (or planets) above the local horizon. Like with the sun & astrocompass, star altitude varies with Aero Navigator position, day of the year, time of day, as well as specific star & its hour angle & declination. There are a variety of ways of determining what the altitude should be for any specific star, but most are very labor intensive. The air almanac & sight reduction tables (such as HO 214) precludes laborious spherical trig computations, and makes the process relatively simple.

Neither the relative nor true bearing of a star are important for a 3 star celestial fix. In fact, the sextant has no azimuth scale. The Aero Navigator must, however, determine the best 3 stars to use. A separation of 120° is ideal, but altitude must be within the practical range of values for the sextant. Obviously if all 3 stars were within a few degrees or near 180° the slightest angular error would result in an enormous error in the distance from the intersections to the actual position. The lower the star is the greater the atmospheric refraction correction. The magnitude of the altitude impacts the distance error per arc minute of sighting error. In a 3 star fix the actual position may actually be one of the triangle corners. If all 3 LOPs are imperfect it may be assumed that errors are equal, even though they may be numerically different; or be in opposition. A realistic assumption that the actual position is in the center of the triangle should minimize the error. Three LOPs can be determined from 3 stars using a sextant; thus a moderate accuracy celestial fix. Although technically there are several ways to establish the center of a triangle, the fix is not precise enough to demand any particular type of solution. An "eye ball" center is adequate. A few that could qualify for this purpose are Trilinear, Kimberling Center, Major Triangle Center, Polynomial Triangle Coordinates & Trilinear Polar. Although technically there are several ways to establish the center of triangle, the fix proper is not precise enough to demand any particular type of solution. An "eye-ball" center is adequate. A few that could qualify for this purpose are Trilinear, Kimberling Center, Major Triangle Center, Polynomial Coordinates & Trilinear Polar.

To select the best triad of stars, the Aero Navigator can rely on his knowledge of the star locations, he can study the star chart, or he can utilize tables in the air almanac. If, however, he wants to reduce the effort he can take advantage of the most modern device available, & use the “Best Sights" function in the handheld StarPilot calculator, which will display the best triads of sights for the observed “sky”. The Sight Analyzer function fits sequences of data to the assumed correct shape so that Aero Navigators can identify the “Best Sights” available. Alternatively the StarPilot software can be loaded into a PC or Lap Top computer for the same benefit. StarPilot software costs less than $150, while the complete handheld StarPilot price is near $400. A sight plan can be performed in seconds. The lunar & solar values can also be computed instantly, & with ease. In either case the navigation calculator provides sights in a microsecond. Actually the price of a full year of Air Almanac in book form is nearly the same as a Starpilot.

4.6.4.2 Practical Considerations

A point of interest in celestial navigation is that the Aero Navigator must have the freedom to move around the sextant, whether it is in an astrodome, or equipped with a periscope. The Aero Navigator must face the star. Since stars are literally scattered all over the sky, & those used for a 3 star fix should ideally be spaced 120° apart, the Aero Navigator must be able to face in virtually all directions. The periscope on the sextant shown in Fig. 37 - 39 could have been designed to rotate within the sextant body to eliminate this requirement, but it was not. The entire periscopic sextant must be rotated as a unit to locate stars. The best that might be done in a small lightplane is to select 2 stars that are each 45° off the nose; thus 90° apart. Properly equipped (astrodome or port) a Beech King Air, D-18 Beech twin or Lockheed Loadstar may be practical, but not most light twins. The periscopic sextant is the only type of sextant that might conceivably be practical for use in a small SE or ME lightplane.

Knowledge of celestial navigation could potentially save your life even without sophisticated instruments.

4.6.4.3 The Value of the Sextant Among Modern Day Aero Nav Devices

Since there are several more accurate Aero Navigation systems, is celestial navigation obsolete??? Far from it.

One nautical expert claims that celestial navigation is still the "most used" navigation system on U.S. Navy ships, except for the GPS. It is used several times per day to back up the GPS; & is the most accurate & important, in the event of major GPS satellite system failure. This particular technically advanced highly accurate celestial nav system is described under Aero Nav Aero Nav system No.22 in this series.

It would certainly be foolish for a serious sailor to plan a round the world cruise in his personal yacht without a GPS, but equally as foolish to leave without adequate expertise & equipment for celestial navigation. Expertise is the key word here. Any serious celestial navigator will tell you that shooting a few 3 star fixes, or taking a celestial navigation course, does not make a person a good navigator. It takes many celestial fixes to gain the expertise & confidence required to consistently locate a plane or boat on long flights or cruises. GPS units fail; power can fail; & on moderate sized yachts, a storm can short out or destroy a GPS, etc.

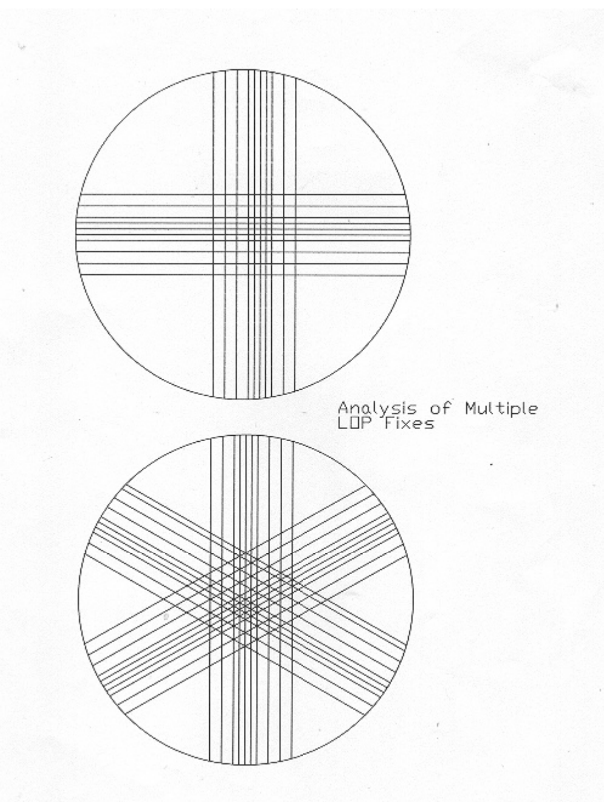


Fig 35: Hypothetical Multi LOP Fix Illustrations

The fact that the author certainly never achieved the status of a celestial navigation expert was reinforced when his errors were proven. An early, shocking LOP experience, proved that any navigation system that provides LOPs must be taken with a grain of salt. More correctly, it should be verified. On one flight he took several 3 LOP fixes. One of these fixes resulted in a triangle with legs about 2 miles long. The other had legs about 50 miles long.

The usual procedure was that the triangle angles or legs be bisected to find the lowest probable error. It seemed that the small triangle would be quite accurate, & the other would most likely be, in fact, near 1 of the 3 intersections. Verification proved that it was the exact opposite. The 2 mile leg fix was in fact quite far from correct; nearly 30 miles off. The 50 mile legs provided a fix that had only a 1 mile error. It certainly was obvious when each was plotted on the course line. Either the GS or lateral displacement from the nominal track would cast doubt on a questionable fix.

The sextant in Aero Navigation is directed at the appropriate identifiable star, while the bubble remains centered. Continuous movement of the altitude control knob will result in a good average of the altitude during the sighting. Some earlier sextants used a pencil to mark a drum periodically. The average altitude was taken as the darkest area on the drum. More modern sextants automated the averaging process. Averaging does measurably reduce the error induced by aircraft oscillations & turbulence. Time of each LOP is taken as the mid time of the observation. Time & altitude must be documented. This process is repeated for the next 2 LOPs. Two of the LOPs are advanced to the time of the last LOP by applying the GS & drawing a parallel line for each. The center of the resulting triangle is considered to be the aircraft position at the adjusted time.

Another method of increasing accuracy would seem to be to shoot multiple LOPs & plot as 1 fix. Fig 34 indicate the difficulty of such an approach. It is possible, but not easy. In a fast moving plane the complexity of advancing a large number of LOPs to the same time seems to make the process prohibitive.

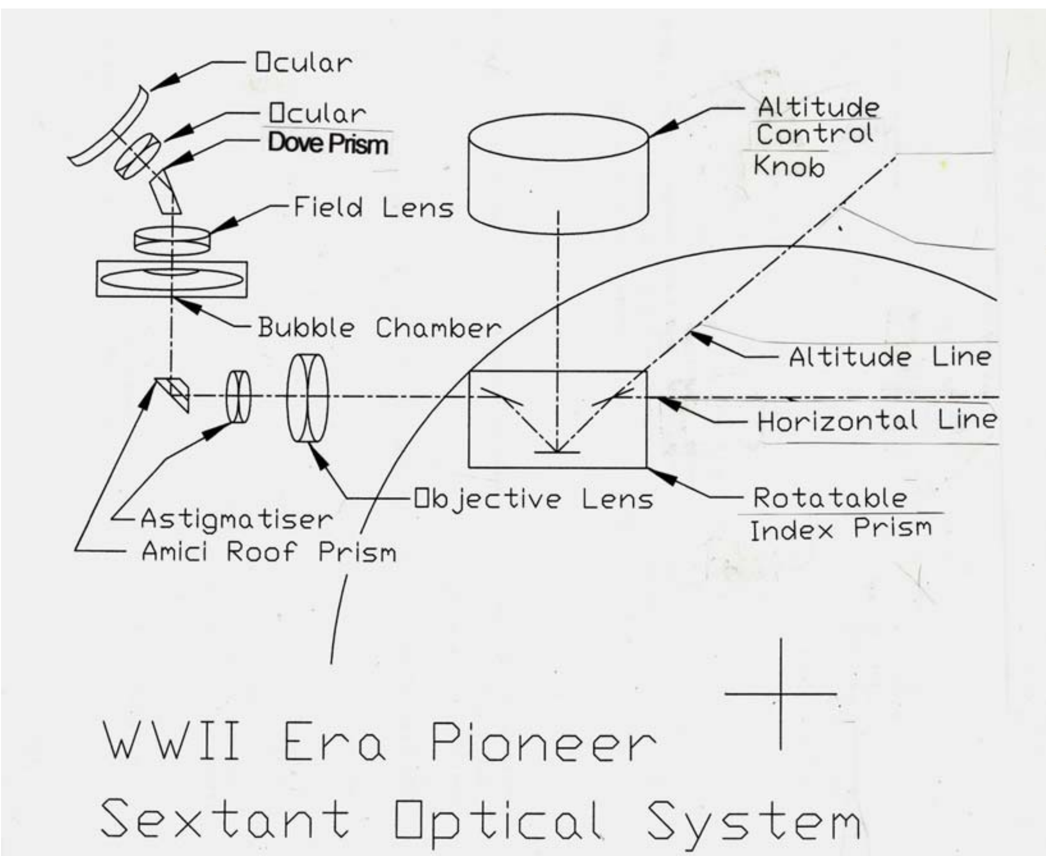


Fig 36 - Optical Schematic of a Typical Sextant

4.6.4.4 State-of-the-Art Sextant Design Details

There are literally dozens of makes & models of modern aero sextants. The Aero Navigation sextant must use a bubble rather than the horizon (which is used by nautical sextants). The bubble must be employed to simulate the horizon because as aircraft altitude increases the true horizon appears to drop. It is no longer a valid reference for the horizontal plane. Increase in altitude also changes the correction for atmospheric refraction. Aero sextants use sophisticated optics to allow the line of sight to pass through the center of the bubble, while keeping the star in the exact center of the bubble by use of an altitude control.

Fig 36 illustrates schematically the optics of a typical hand held Aero Navigation bubble type sextant that is normally used under a clear plastic bubble. In this schematic an Amici roof prism provides for laterally reversing & inverting the image, while a dove prism permits rotation of the image inline. The rotatable index prism allows precise change in line of sight from near the horizontal to near the vertical.

Fig 37 shows a similar vintage sextant.

The schematic & a few sextant photos illustrate internal & external design details:

4.6.4.4.1 Design Details of a Periscopic Sextant

Fig 38 to 40 show 2 quartering rear views & a front view of a WWII military surplus Kollsman P/N 1471C-02 periscopic sextant.

The quartering rear views look beyond the rubber eye shield toward several controls, & show some details. These indicate just how much more complex the Aero Navigation sextant is than the nautical sextant, although the complexity is internal, rather than external as in the nautical sextant. The author purchased this surplus sextant to enable him to provide high quality illustrations for this course. Many Aero Navigation sextants observe stars directly rather than through a periscope. Without a periscope an astrodome (large plastic bubble) is required, which introduces additional imperfections that refract the entering light rays. The periscopic sextant requires only a small port that can accommodate pressurization of the cabin.

In Fig 38 the quartering left rear view shows a large serrated aluminum knob that controls bubble size. Slightly forward & well below the large black knob is a deeply indented knob, calibrated in units of 0 to 9, that selects from a series of filters

Fig 37 Photo of a sextant similar to that shown in Fig 35; This sextant appears to be a WWII vintage aviation type sextant; model AN 55851-1.

that permit adjusting the apparent heavenly body brightness per the user's choice of optical filter. Above the large aluminum knob is a small lever that inserts or removes an optical diffuser.

In Fig 39 the quartering right rear view shows a large serrated aluminum knob that controls altitude value. Below & to the right of this knob is a coarse altitude window display; in this photo 33°. Slightly forward & well above are 2 small knurled aluminum knobs that retain small light bulbs for internal illumination, & just above the eyepiece is a plastic knob that controls brightness by use of a rheostat.   Above the 33° course altitude window are 2 adjacent round discs (semicircular portions are visible) that read finer altitude values. The claw-like stamping to the right of the base of the periscope is the watch holder, in full view of the observer. When ready to shoot a star he must note the mean time of the observation to proper position the LOP along the flight path, & thus produce meaningful fixes. In this particular sextant he presets the desired duration of the observation, so he can add half of that time to the start time of the watch as he starts the observation timer.

During the set-up for each observation, the Aero Navigator must adjust the large serrated aluminum knob to the left of the eye shield (Fig 38) for what he considers to be optimum bubble size, & verify that the bubble is intact (not broken into 2 separate bubbles).

The next step is to preset the large silver elevation control knob to the right of the rubber eye shield so that the mechanical counter forward of that knob reads the anticipated star altitude (Fig 39) .

The mechanism automates the averaging process & allows the elevation to be read at the completion of the preselected 30 second to 2 minute observation period.   The mechanical counter reads elevation from zero to 92° 30'.
The closer he can keep both bubble & star centered during the observation period the more accurate the altitude reading will be.

Collimation & field errors can also degrade results. Instrument calibration & bubble acceleration errors should be corrected. The instrument cal. error can be eliminated by mechanical adjustments. Acceleration errors depend on turbulence & aircraft oscillations. A bubble indicates level only when stationary, or moving at a uniform speed, in a straight line.   Precession and mutation corrections are normally negligible. Coriolis error is negligible for practical purposes for celestial Aero Navigation. It seems to the author that the effect of earth motion on any moving object should not be named at all. Water in a drain swirls like any low pressure area in any fluid, because, to consider only the Northward movement, the Eastward movement is faster than it would be as it moves to the North because the absolute velocity of any object on the earth is higher near the equator than as it moves away from the equator. That causes the

Fig 38 - Quartering Left Rear View of Kollsman Periscope Sextant; WWII Vintage

Fig 39 - Quartering Right Rear View of Kollsman Periscope Sextant; WWII Vintage

Fig 40 - Front View of Kollsman Periscope Sextant; WWII Vintage

4.6.4.4.2 Operation of a Periscopic Sextant

Northward moving water to appear too fast as it approaches the low pressure area at the center of the drain, & bend to the right, resulting in a CCW rotation; Coriolis .

4.6.4.5 Influence of Time on Observer Position

The front view (Fig 40) shows slanted observation window & small internal lens atop the periscopic post. On the front of the housing are the timer winding & start control levers.

Fig 41 shows 1 of 8 official star charts; summer stars. It also shows the North & South Poles. Similar autumn, spring & winter charts are also available, along with Circular Polar charts. A full star chart shows the entire sky; much like a world map. These charts name the stars that are commonly used for celestial navigation, & are part of an easily identifiable grouping of stars, called constellations; each of which has a name.

Impact of "time" inaccuracies on fix accuracy was noted in paragraph 4.5.1.1 under the previous Aero Nav system on the solar LOP. What is most important is the fact that a 1 second timing error results in a 1/4 minute of longitude or 1/4 NM position error.

:

4.6.4.6 Identifying Stars:

The constellation names appear all in upper case letters; URSA MINOR, URSA MAJOR, LEO, etc. Planets cannot be shown on a star chart because they remain in orbits, like the earth, so are not fixed in relation to the stars relative to the earth. The polar charts show only the Northern (or Southern) Hemisphere. URSA MINOR contains Polaris; the North Star.

The author used Polaris to establish fixed sighting points to establish true North before pouring a free form concrete patio to anchor the modern elongated bronze compass rose that he designed & plasma-cut. It is less than 100' from his

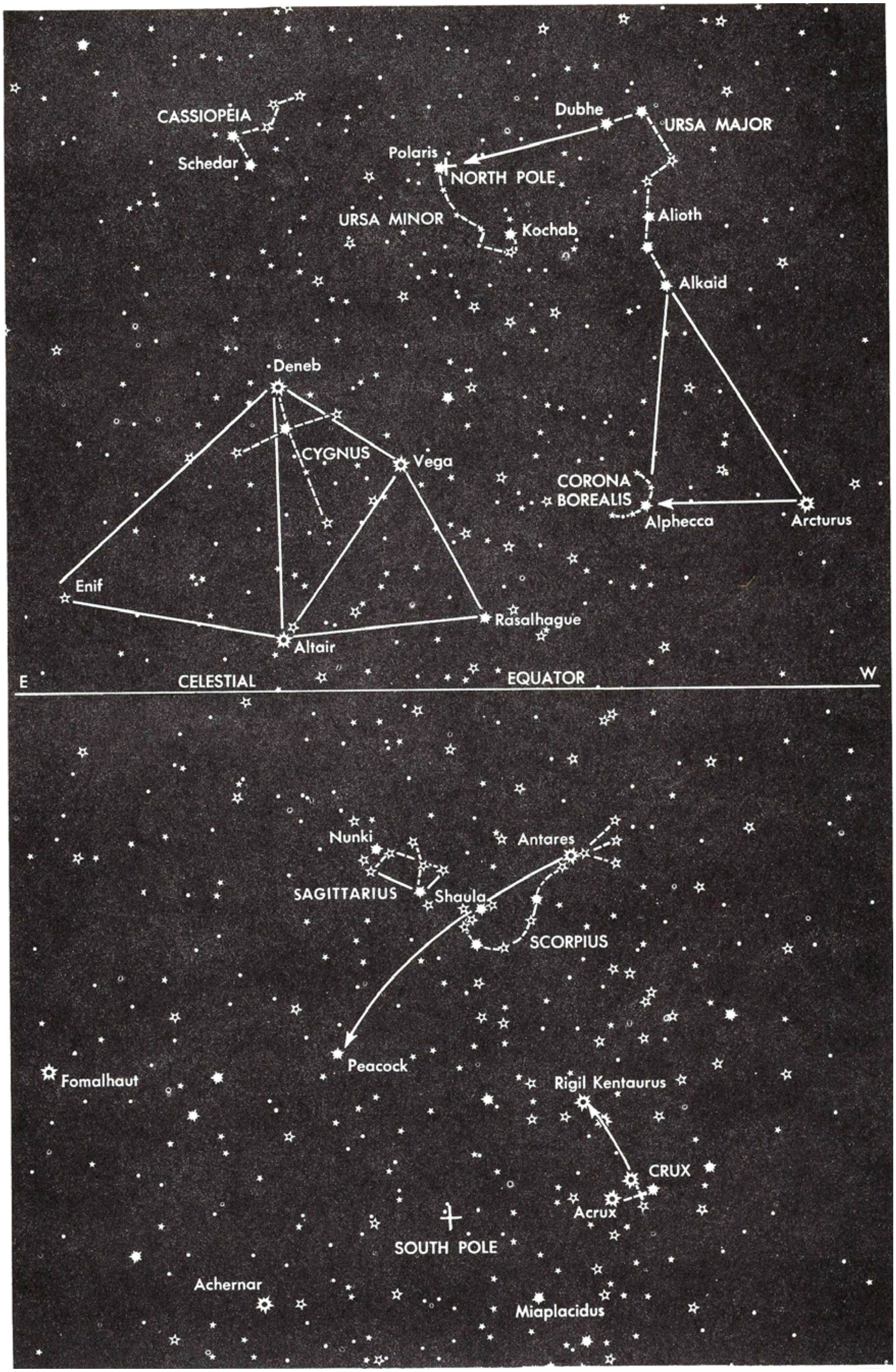


Fig. 41: Summer Star Chart

bulkhead at the edge of Galveston Bay. Polaris was helpful because the concrete bulkhead along the bay actually runs

20° while it appears to be North (N-S). With rebar galore before the pour, even a master compass was unreliable.

There are many stars that are used for celestial navigation. The above summer star chart shows Ursa Major near the top right, & Ursa Minor below that. The other 3 seasonal star charts also show Ursa Minor. These charts name the stars that are commonly used for celestial navigation, & are part of an easily identifiable grouping of stars, called constellations, each of which have a name. The constellation names appear all in upper case letters; URSA MINOR, URSA MAJOR, LEO, etc. The 2 stars that form the end of the big dipper (Ursa Major) point to Polaris, which is the North Star, & located on the end of the handle of the little dipper (Ursa Minor). Polaris is generally considered to be fixed at the North Pole. In reality, it circles the North Pole at 3/4° away. Thus a sighting of Polaris with no almanac or even a watch will never be more than 3/4° off. Since it circles the pole, it will be precisely aligned above the observer's meridian twice per 24 hour day (once over the observer's upper branch, & once over the lower branch, & 3/4° left or right 6 hours from either of these times. When aligned with the observer's upper or lower branch, the altitude was + or minus 3/4° from the far left or right branches. A full star chart shows the entire sky; much like a world map.

Another factor in facilitating location & sighting a star for celestial navigation is its magnitude (brightness). Magnitude & parent constellation are given in parends for a few of the more popular stars that are commonly used for celestial navigation: Achernar (Pegasus, 0.6), Acrux (Crux, 1.1), Aldearan (Taurus, 1.1), Alpheratz (Pegasus, 2.2), Antares (Scorpius, 1.2), centaury (0.9), Betelgeux (Orion, 0.1-0.2),Capella (Taurus, 0.2), Deneb (Cygnus, 1.3), Denebola (Leo, 2.2), Diphda (Pegasus), Dubhe (Ursa Major, 2.0), Kochab (Ursa Minor, 2.2), Polaris (Ursa Minor, 2.1), Schedar (Cassiopeia), (Shaula (Cassiopeia), Sirius (Orion, 1.6), & Vega (Cygnus, 0.1); most omitted. Magnitude is expressed in first magnitude, second magnitude, etc. First magnitude covers the range that included 1.0 M1 is nominally the brightest star in the sky; Sirrius, at M1.46, is the brightest in the sky. Pogson's ratio just happens to be the same as the difference between each adjacent magnitude; the fifth root of 100, or 2.512. A M6 is the dimmest that can nominally be seen by the human eye. A person can see a M25 through a very good telescope. The Hubble telescope can see up to about M30. Obviously the larger the "M" number, the dimmer the star.

Planets are less useful than stars, but some are listed in the air almanac, including the moon: Jupiter, Mars, Moon, Venus, & Saturn.

Aries is the point where the sun crosses the equator at the Vernal equinox; not a star, but an important point in the celestial sky. Its GHA is listed in the air almanac, & is considered to be a part of the constellation Ram.

4.6.4.7 Three Star Fix by Sextant:

Fig 42 is an example of an Aero Navigator's plot of a "standard" three star celestial fix. It is shown with an enlarged balloon for clarity:

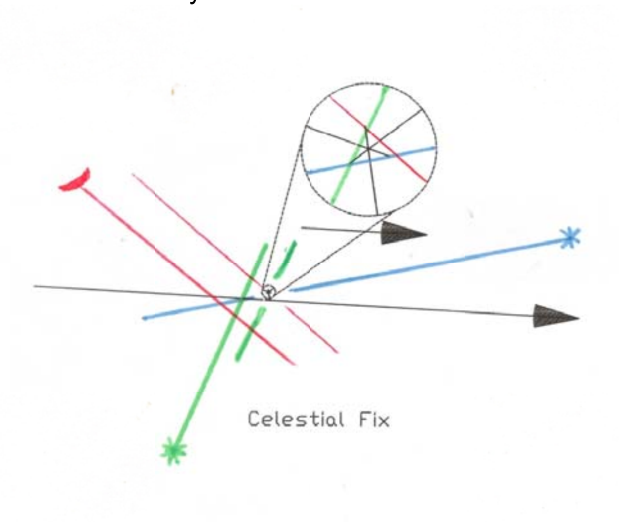


Fig 42: Three Star Celestial Fix

●The ground track is shown with a large black arrow head pointing in the direction of flight.
●The moon & its LOP & offset are shown in red. It was shot first, so its offset is twice as large as that of the second LOP.
●The second LOP & its star are shown in green.
●Since the last LOP, shown in blue, was used as the time of the fix, it was not necessary to offset it.

●Both offsets are drawn after the final fix, so that all 3 times are known. The offset is obviously established by multiplying the GS by the time between the LOP & the final LOP.
●It is obvious that when a 1 second timing error results in a 1/4 mile position error, the timing & offset demand the greatest of care. This obviously adds to the complexity, & opportunity for imperfect LOPs & fix.

If the plane is cruising at an assumed GS of 200 kts, & each sighting (of 1 LOP), including set-up & documentation, takes 6 minutes, the plane advances 200/(60/6) = 20 NM. The first LOP line then must be advanced 40 NM while the second LOP must be advanced 20 NM.

The small triangle formed by the 3 LOPs (2 offset) represent the actual fix. But the center is the fix, so either the sides or angles must be bisected to form the 3 lines that intersect closer to a single point. The expanded view of the fix clarifies the above. In this case, the fix falls to the left side of the intended track.

Not shown here, an actual fix would be at a specific point along the track, so the GS may also have been imperfect. It is possible that the computed position would fall several NM further to the right or left of the fix in this view.

A typical good celestial fix will be within 1 NM of the true aircraft position. Greater accuracy could be achieved by repeating the fix as soon as the first one has been plotted.

4.6.4.8 Taking Advantage of the best of the characteristics of both AstroCompass & Sextant.

Another method of obtaining a fix from a single body like the moon would be to take an angular (azimuth) measurement using the AstroCompass while another Aero Navigator takes a simultaneous LOP with the sextant. Alternatively, one Aero Navigator could shoot both & adjust 1 for time. Since the sextant does not measure azimuth, & the AstroCompass only approximates altitude, it is not very accurate, the Aero Navigator takes advantage of both. It is obvious though that 2 LOPs at 2 different times form the same heavenly body would not actually provide a fix. Two parallel lines, after offset, "should" be coincident. Actually it could provide either GS or lateral course alignment, or some indication of each, depending on angle between LOP & track.

4.6.4.9 Circles of Equal Altitude

Fig 43 illustrates circles of equal altitude. Each celestial sextant sighting results in a specific altitude. The cones in this illustration represent very large circles on which an Aero Navigator would be located when he measures that particular cone half angle as Hs (observed altitude). He could be East, West, or any other direction from the sub-stellar point; the point directly under the star. He will certainly be at some point along the circumference of that circle. He should have some idea of where he is, so can narrow his position down somewhat. If that circle crosses over a land mass, & he is on a sailing yacht, he knows that he is not on a portion of the circle that lies on the land. The diameter of the circle is typically hundreds or thousands of miles. As a result, the circle of equal altitude can be practically drawn as a straight line, since it is always such a large radius that it is effectively a straight line.

If he shoots a second LOP he will almost certainly know which of the 2 intersections he is located near. The 2 intersections will most likely be hundreds or thousands of miles apart. If he wants a more accurate fix, as he should, he will shoot a third star. The resulting third circle will intersect each of the previous circles at 2 points. One of those intersections should be very close to one of the first 2 LOP intersections. He will select the only set of intersections that are in the vicinity of his known position. That set of intersections will form a triangle with minutely curved sides. Standard practice is to assume equal error, & locate the center of that triangle by bisecting angles or side lengths to create another intersection of 3 lines. The new intersection should be a single point, although it may be a smaller triangle. In either case it is considered to be the fix; or position. A triangle such as the one in Fig 41 will confirm the best known location. It shows a plot of a celestial fix. But just how is the fix plotted; from the star sub point, which may be thousands of NM away? The intercept method?

It would seem easy enough to draw an arc to plot from the sub-stellar point to the assumed position of the plane. But if the sub-stellar point of the star is 2,000 NM away, the radius of the circle of equal altitude is 2,000 NM, so a plot would be either meaningless or impossible, depending on the chart scale. An example from haversine computation: Given star over mid Atlantic ocean, & observer near the Northern border of Wisconsin; star at 30° N x 30° W, observer at 50° N x 90° W; produces a great circle distance between the sub-stellar point & the observer's position is 2916 NM. A 30" square chart, large enough to allow 3,000 NM to be plotted, would not have a resolution of less than 10 NM. Only a bar compass would serve to draw such an arc; dividers capable of opening to 30" would be too unwieldy, as would a 30" square chart table in most planes.

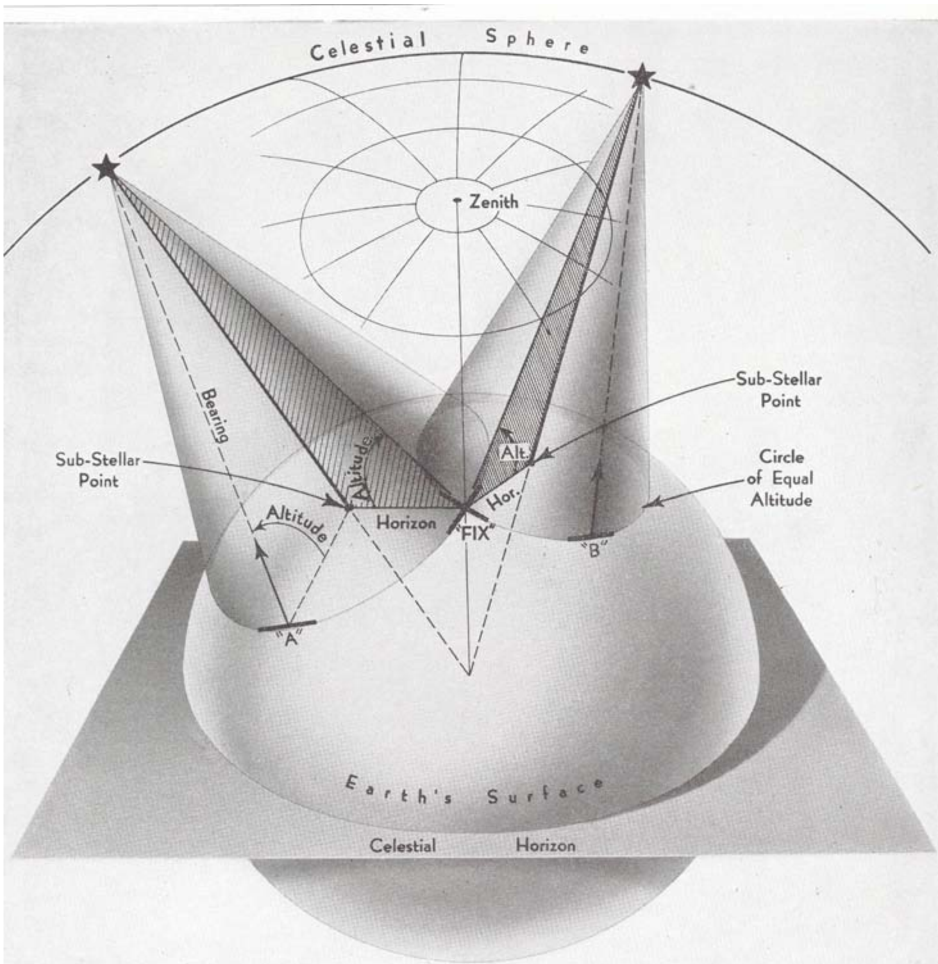


Fig 43: Circles of Equal Altitude

If the earth were flat, like the chart, it would be easy to compute from lat-long of aircraft position & subpoint the distance. More realistically the air almanac, & HO214 or later sight reduction tables, could be used in a manner similar to that shown in the sample problem of Fig 34.

4.6.4.10 The intercept Method

The intercept method is based on the subpoint method. The intercept method was once called the azimuth intercept method because it called for drawing a line that intercepted the azimuth. One of several variations of this method is as follows:

Consider the plane to be at a specific true bearing (Zn) from the star being observed. The astronomical triangle may be solved by use of astronomical tables. Use the information available including the celestial tables to determine Ho, Zn & Hc; assuming the plane is at a specific DR position. Compute the difference between Hc & Ho. This is called the intercept distance. This distance is given in arc minutes. Since 1 arc minute = 1 NM the difference between Hc & Ho is equivalent to distance in NM. If Ho is greater than Hc the plane is closer to the subpoint, so the intercept is measured toward the subpoint. If Hc is greater than Ho the intercept is measured away from the subpoint. A helpful limerick is: HoMoTo.

A joint graphical-tabular example of an intercept method of establishing a LOP is:

DR position shows plane at 121° 30’ W long & 38° N lat.

An Aero Navigator used a sextant to obtain Ho = 32° 14’ & Zn = 120° at 1015 GMT.

Ho - Hc = 15 NM away (15' A).

Plotting requires setting the Weems plotter to 120° (CW from true North), & measuring 15 NM away from the 120° LOP direction. Dividers are more practical than the Weems plotter scale in this case. With Weems plotter aligned to 120° measure 15 NM "away". Hold the second pointer of the dividers & slide the Weems plotter against it. Rotate & slide the Weems plotter so that the angular scale can be used to read 120° on a parallel of latitude great circle & draw along the plotter from the divider point to establish a line parallel with the plotter & displaced 15 NM. This offset established the desired LOP 15 NM away in the 300° direction. See Fig 44 for illustration of the above 3 step process of drawing one LOP using the intercept method. Repeating the process for 2 more LOPs give a celestial fix by the intercept method. The 3 LOP fix will look like that of Fig 42.

4.6.4.11. Limitations of Celestial

There are 2 serious problems in Aero Navigation above 70° latitude:

The magnetic compass is unreliable, as discussed previously.

For very high latitudes plotting on any chart, including celestial fixes, is difficult because of the small meridian convergence angles. A change to Grid Navigation practices is thus preferred. Grid Navigation is discussed in Aero Nav system No. 15 in this series.

Celestial Aero Nav is laborious & time consuming.

Presetting the sextant for the anticipated star (or planet) altitude will simplify & expedite location of, & alignment with the star.

4.6.5 Interesting Historical Facts Involving Sextants:

The A-Bomb

In 1942, during WWII Link (earliest manufacturer of flight simulators) sold the U.S. government hundreds of A-12 sextants per week at $262 each. Cheaper than a new car, but a brand new 1940 Chevy sedan sold for around $850. Car sales to the public ceased after the cowardly attack on Pearl Harbor Dec 7, 1941. In August of 1945 Dutch Van Kirk used an A-12 to Navigate the B-29 named the Enola Gay on the long flight across the Pacific and back. They, of course, dropped the first 2 A-bombs on Japan on that trip. Japanese historians & military experts agree with similar American experts that those 2 bombs actually saved far more Japanese lives than it took. Plus, of course, tens of thousands of American lives. One month later the A-12 was placed on the (WWII) surplus. The A12 looks much smaller & simpler than similar U.S. & British sextants; more like the old banana shaped magnetic coating thickness gage. The A-12 is still on the collectable market on E-bay for considerably less than original new cost; in 2009 dollars vs. 1942.

Lindbergh

Anne Morrow Lindbergh studied celestial Navigation in preparation for their 1933 aerial route survey flights for Pan American Airways. The sextant she used was the third one off the line of Pioneer Instrument (S/N 3) Model 342. It appeared to be smaller than the typical Aero Navigation sextant.

4.6.6 Interesting Quotes from Sea Farers Who Warmly Received Celestial Navigation When First Introduced.

A quote that obviously pertains to sailors of old could certainly apply to many Aero Navigator-Pilots of planes, too:
"And all I ask is a tall ship and a star to steer her by, and the wheel's kick, and the wind's song, and the white sail's shaking..."—John Masefield, *Sea-Fever* "

A ship's captain once said "these are two of the most beautiful lines ever penned about sailing and the sea."
One might say sailors & pilots are in the same brotherhood. Most who fly find it captivating & impossible to abandon. Likewise, sailing with only wind in the sails has an even greater similarity to, & attraction of sailplanes. Both are truly a joy as well as a challenge.

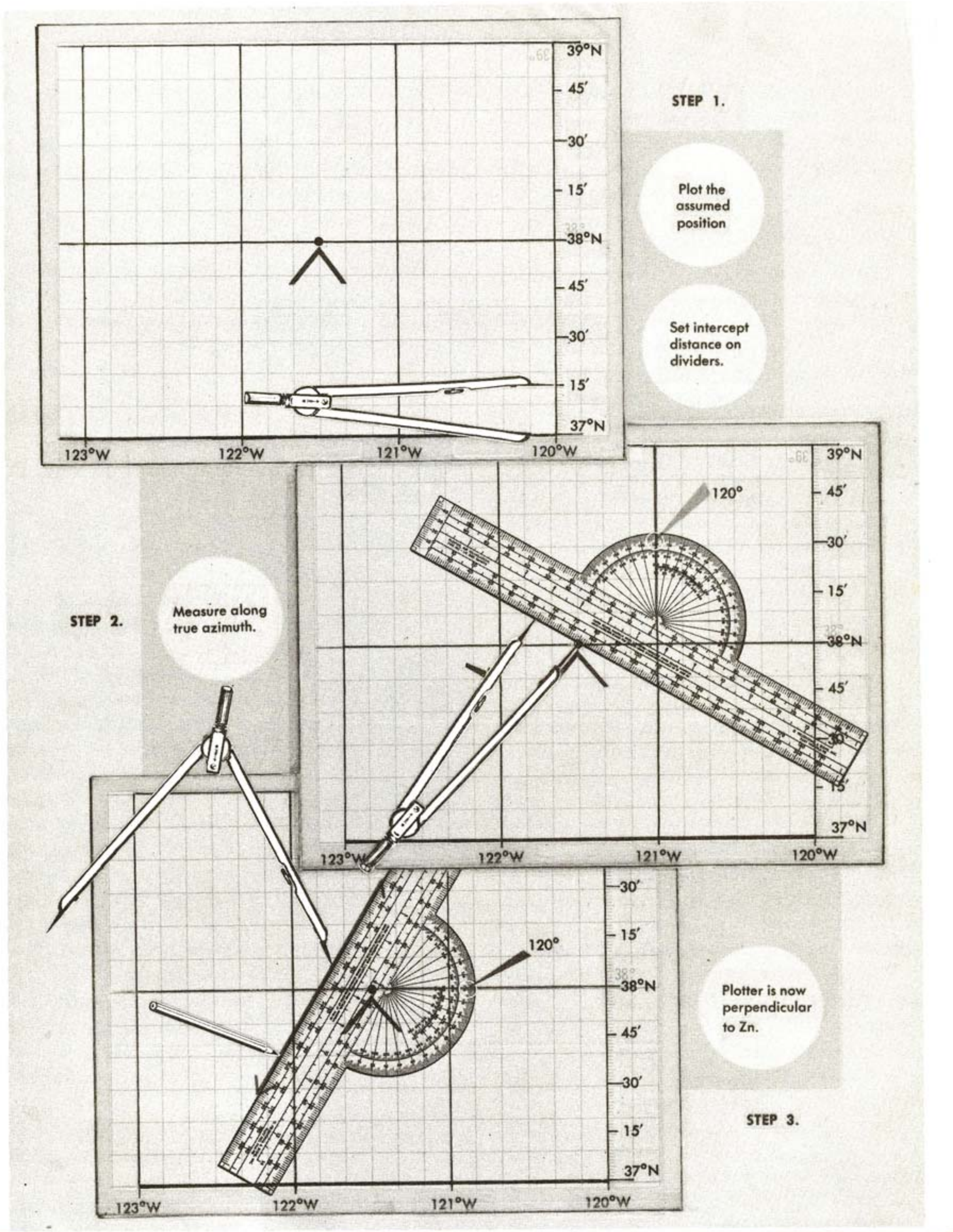


Fig 44: Graphical Solution to Intercept Method of Celestial Fix

4.7 Aero Nav. System No. 7: Non Directional Beacon (NDB)

4.7.1 Background

Radio direction finding was 1st used in World War I to locate enemy positions on the ground; before any aviation or commercial application were implemented .

Soon after the low frequency radio was applied to aviation in the 1920s, it was found that it had excellent Aero Nav potential.

A nondirectional transmitting antenna radiates radio energy equally well in all directions. A nondirectional transmitting antenna is typically a small diameter vertical metal mast, mounted atop an elevated tower to reduce blockage by nearby obstructions. The small diameter antenna has a nearly zero top surface area, and radiates comparatively little energy directly above the mast. Most energy radiates uniformly around the antenna.

This capability was significantly improved by each of several developments that led to a system that is still very important for many Aero Nav. applications. Each step was truly revolutionary. These steps were:
a. Homing based on the relationship of audibly detected changes in signal strength was very limited in capability. It was very difficult to use, & unreliable. Turns improved or degraded audibly detected reception for a general idea of station RB.
b. A major advancement was made when the loop antenna was adapted to aviation. It could be mounted for maximum signal strength when heading directly toward the transmitting station. A weakness was that the directional characteristics were ambiguous. It was impossible to tell immediately whether the transmitter was in front of or behind the plane. Only audible signal strength detection was available to remove the ambiguity. That technique was slow & imperfect; especially when thunderstorms were in the vicinity of the transmitter or plane.
c. A still greater improvement was when the loop was mounted on a rotating base. The loop was then manually rotated to locate RB offering the loudest signal. This was called a Radio Direction Finder. One problem was that the loop provided equal signal strength in front of & behind the loop. The 180° uncertainty could be eliminated by turning, preferably 90°, & observing the advancement or retreat of the pointer.
d. Another major improvement resulted when the loop was automatically rotated electrically by sensing signal strength & powering the loop to achieve maximum strength. The ambiguity remained. This was called an Automatic Direction Finder.
e. The most advanced ADF was introduced in the late 1960s with the solution of the ambiguity problem. This NDB treatment will be a valuable Aero Nav system for the foreseeable future. It used advanced electronics to eliminate the ambiguity. The smaller solid state loop provides an unambiguous bearing. A reading of 30° will no longer be confused with 210°. It was also much smaller & lighter in weight. The reduced size resulted in reduced aerodynamic drag.

Rotating the plane of the loop antenna so that it is parallel to the line between the transmitter & aircraft, maximum voltage is induced in its coils, resulting in maximum signal strength. Rotating the plane of the antenna perpendicular to the line between the transmitter & aircraft, minimum voltage is induced in the coil, so the signal strength is minimized. These characteristics give the loop antenna its ability to quantitatively sense the relative bearing to the transmitter.

A "small" loop has less than 1/4 of a wavelength in circumference. Directional receiving loops are typically 1/10 of a wavelength without correcting electronics that allow a comparatively small loop to appear electrically to be, in fact, very large. The effective voltage of a small loop is measurably increased by use of a tuning capacitor to achieve resonance. The small loop is actually more sensitive to the magnetic portion of an electromagnetic wave. Properly shielded, it is thus less sensitive to electrical noise than a straight wire antenna.

There are a variety of disturbances of electromagnetic radio signals. The most common & serious for the lower frequency bands are caused by electrical activity (lightning) within thunderstorms. AM (amplitude modulation) signals are quite susceptible to electrical disturbances. FM (frequency modulation) is nearly immune to electrical disturbances.

There are 3 general types of electromagnetic: Radio waves; direct waves, sky waves, & ground waves. Transmitter frequency & power determine the reception distance.
● Low and medium frequency bands travel several hundred miles as ground waves, following the surface of the earth. Increasing transmitter frequency decreases quality of reception & ground waves deteriorate.
● Frequencies at & above VHF ground wave reception is limited to only a few miles, but direct waves can be useful for

line-of-sight transmission.

● Sky waves are refracted by the earth's atmosphere. Radio communication for distances greater than a few hundred miles rely on sky waves.

● Direct Waves do not bend, so may be received only by line-of-sight path between receiver & transmitter. VHF, UHF, and higher bands are useful only for very short distances except when the transmitter or receiver is elevated on a mountain top, or in a plane on the use of direct waves.

● Fading can also occur when a single transmitted signal arrives at a receiver as both a ground wave and a sky wave. If the two waves arrive in phase the signal will be stronger since they reinforce one another. If they arrive in opposing phase, they cancel one another.

● Another influence on transmission distance occurs near sunset & sunrise, & during the night. Ground waves and sky waves overlap because of rapid changes occurring in the ionosphere, causing a polarization error. This can result in confusion over which signal is being received.

Mountains & buildings block or distort LF signals, although this is rare.

Occasionally local areas of natural magnetic disturbance disrupt ADF signals

The RDF & later the ADF has been one of the most useful Aero Nav systems since the 1920s. It has a major advantage in 1 respect over the excellent OMNI system; that of usefulness over extremely long ranges. OMNI is line-of-sight. ADF is limited only by transmitter power. There are situations where it is the only viable Aero Nav system while over mid ocean; & potentially even within the U.S. The availability of transmitters is nearly unlimited, so many more options are available for direct homing to a point near nearly any town or city in the US.

4.7.2 Theory

The theory of the NDB is simple. Any RF transmitter sends a signal that is often intended for other purposes than Aero Nav. Others are devoted only to Aero Nav. Any receiver that is equipped with a directional antenna can indicate the relative bearing from the plane to the transmitter.

4.7.3 Accuracy & Efficiency

The modern application for any NDB uses the ADF to provide a RB (relative bearing) from the plane to the transmitter. The RB is accurate to an angle of no larger than 5°; possibly as small as 2°. As was discussed previously, a 1° error translates to a 1 mile error at 60 miles. If homing in on a transmitter, that error is minor, since it will lead one to the transmitter. One concern is discussed under paragraph 4.7.4; Application, below. If using a transmitter that is 180 miles away from the destination, & the ADF error is 2° his LOP will be 6 miles from the destination.

If the Aero Navigator is flying cross country by use of NDB, he can stay on course per these values. Homing can be per above & below. Cross radials will have an error per above. If a standard broadcast station is 1 mile away & he has a 2° error, the progress along the track will be within 200 ft.

The ADF is important as an instrument approach Navaid in isolated locations. It is used extensively as a marker, or for cross track in some other instrument approaches.

If using the ADF for staying on course the Aero Navigator has full freedom to fly a direct path. There is no obligation to follow the devious course of airways; thus the ADF is an efficient Aero Nav system.

4.7.4 Application

4.7.4.1 Navigation by use of the ADF

The ADF can be to determine time & distance to transmitter, intercept a bearing, homing, tracking inbound or outbound, & for instrument approaches.

4.7.4.1.1 Determining the NDB Bearing Involved in Flying with the ADF

The need is to fly a specific TC; or MC. Wind drift correction provides a TH or MH.

The ADF provides a RB (Relative Bearing). It actually depends on whether the ADF has a fixed or movable azimuth scale. How do these relate to provide the necessary information?

Magnetic North is the reference direction.
MH of the plane is the angle measuring CW (clockwise) from Magnetic North to the aircraft.
RB is the angle measuring CW from aircraft heading to the NDB transmitter.
MB (magnetic bearing) is the angle measuring CW from Magnetic North to the NDB transmitter.

4.7.4.2 Homing

4.7.4.2.1 With no wind, homing is quite simple. Just fly with the needle pointing straight ahead.

4.7.4.2.2 With a crosswind component, it is possible to home, but keeping the ADF indicator needle pointing directly at the NDB would cause the plane to drift progressively further off course, a shown in Fig 45. It would require a continually changing heading. This will result in flying a curved path with ever decreasing radius of turn. These changes will result in flying a longer distance. It will thus take more time. The continuously changing radius of turn will also require progressively closer attention as it approaches the NDB.

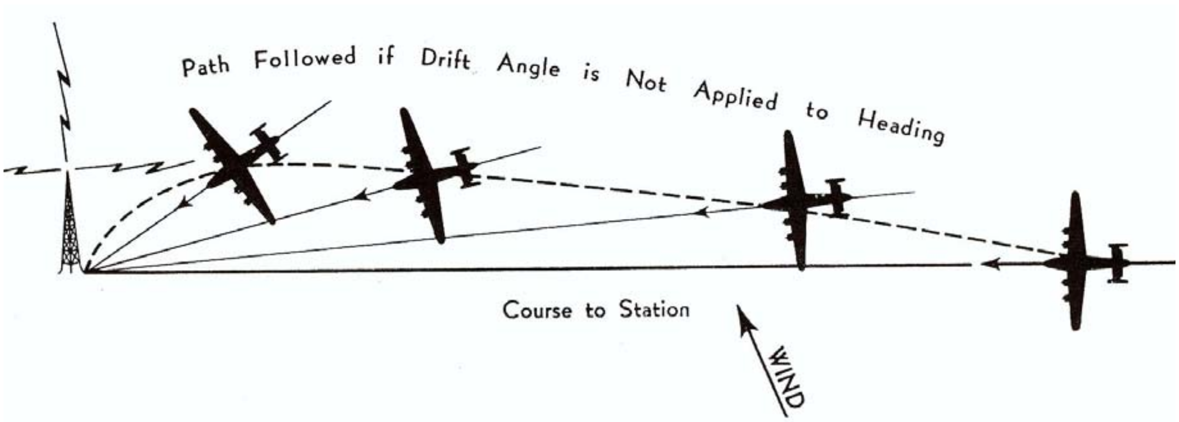


Fig 45: Indicates the Path Flown by a "Lazy" Aero Navigator's Approach to Homing.

4.7.4.2.3 A better way to "home" using an ADF is to fly directly toward the NDB until the drift angle can be established. Then apply the drift correction & fly the assumed correct RB, & track directly to the transmitting beacon, as shown in Fig 46

4.7.4.2.4 The preferred way to "home" using an ADF is to call FSS or otherwise obtain W/V. Using the E-6B, W/V, & aircraft performance data, perform a preflight to determine drift & GS. Apply drift to TC & establish the correct MH to track directly to the transmitting beacon.

4.7.4.2.5 Another example of the above on "homing" using an ADF is per the following:

Fly the preflight heading (assume 120°) which should result in the ADF needle pointing directly forward relative to the aircraft longitudinal centerline. With an unknown crosswind the needle should move as the plane drifts off course.

After holding 120° for half an hour, assume that the Aero Navigator notices the ADF needle is pointing to 125° RB (5° change in relative bearing). The plane must have drifted left to cause the ADF pointer to turn CW. See alternative in below paragraph, or apply corrections from this point on. Turn 4 x 5° in the direction of the pointer movement pointer reads 20°, for a new heading of 140°. That should overcorrect to bring the plane back to the course line in half an hour. When the plane is back on course the pointer should read 20° left of the plane heading. Turn back to 10° toward the original heading, to 130°.

If following the exact track, a more efficient alternative would be to apply a smaller initial correction angle to fly directly from the off-course position to the destination. If the total flight was to be 1 hour, the half hour fix with 5° drift could be corrected by changing to a heading of 130°.

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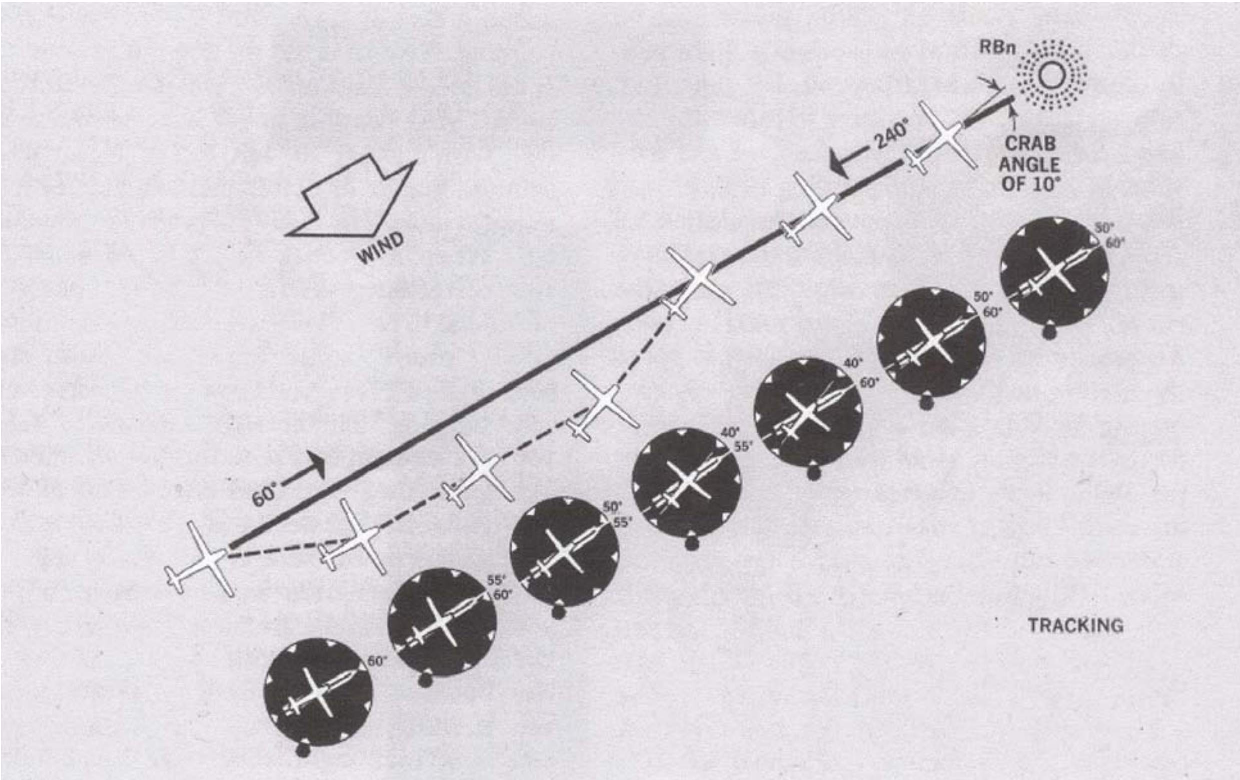

Fig 46: The Sequence for Establishing & Correcting for Drift While Homing to a NDB by use of the ADF

4.7.4.3 Dual ADF Fix

4.7.4.3.1 Locating & flying to a point within reception range of 2 NDBs is most efficiently accomplished by spending time during the preflight to establish desired RB, MB. or TB for each NDB at a series of locations along the track. As the flight progresses the distance off course can easily be established & a CH correction applied.

4.7.4.3.2 Fig 47 illustrates the RB & TC for each of 2 NDBs. Both happen to have the same RB (35°), & would for all flight along this particular TC (360°). It is unlikely that the 2 NDBs would be located so conveniently as the mirror image. With a mirror image arrangement, the extensive prefight effort mentioned above is not justified. The 2 RBs should always be identical, making the course in Fig 47 easy to maintain. It is most convenient to turn the ADF knob to a RB of zero regardless of the TC to the destination. With the ADF set as suggested, the mirror image RBs will be equal. That is easier than to have unique values that are difficult to reconcile. A more likely flight would require a few preflight RBs listed on the chart; or a log. If the Aero Navigator finds, as he progresses on this flight, that the 2 RBs are unequal, he must determine which side of the track he is on, & then correct by analyzing the new angle to destination W/V error to reach off-course point. Techniques discussed in DR & other courses suggest that this is an easy analysis to perform.

4.7.4.3.3 This application whether mirrored or not, illustrates a practical merit of ADF over VOR; the pointer always points directly to the station, so whether equipped with a fixed or the more popular rotating dial, the ADF requires no knob twisting for tracking or establishing a bearing or a fix. The only OMNI that does not suffer from this problem is one like the Collins Microline, which has both digital display & standard analog CDI needle. The OMNIs that offer only bearing; by digital display, suffer from an even more serious limitation that handicaps operational interpretation; especially important for IFR.

4.7.4.4 ADF Fix by Timing While Homing

4.7.4.4.1 When homing toward NDB, & at an unknown distance away, turn 90° & note bearing. Upon reaching or completing a 10° bearing change note time & turn back to original heading & continue homing. Apply the simple equations:

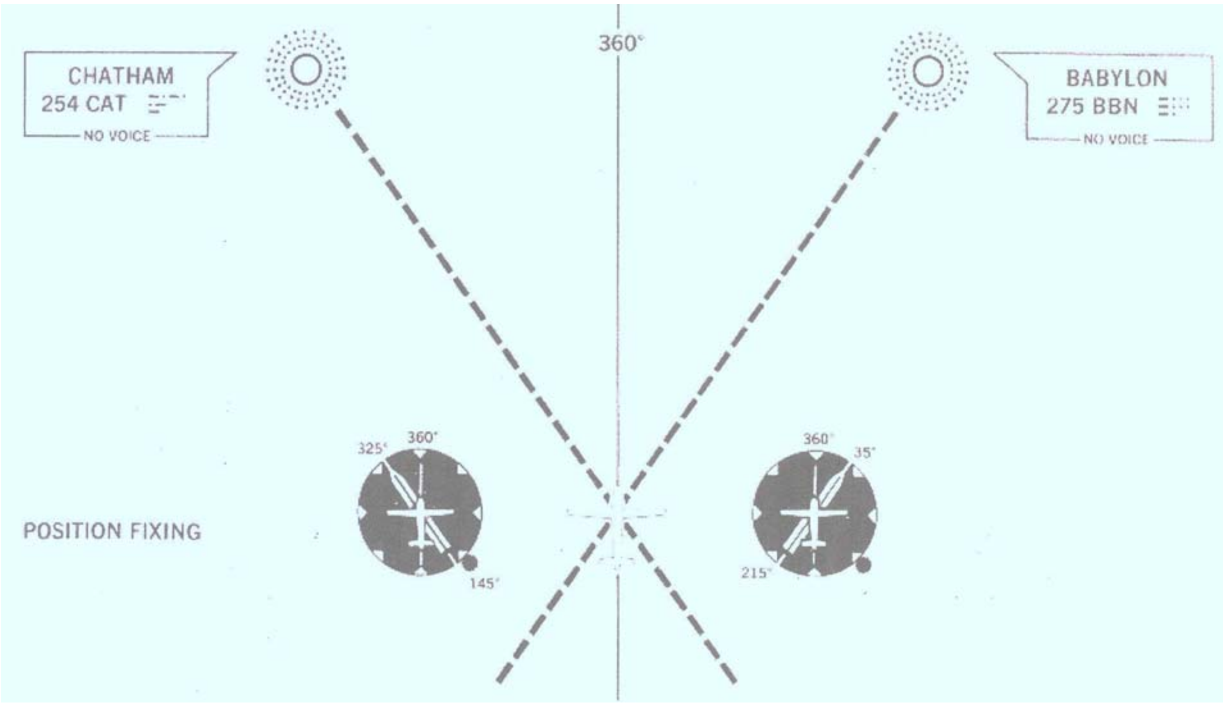

Fig 47 : Dual ADF Fix

M = S / A & N = TM/A.

where M = minutes to NDB, S = time in seconds flying on off-course heading, A = angle flown off course,

N = NM to station, T = TAS.

Given 220 seconds to fly 10°, & 110 TAS:

M = (220/10) = 22 minutes from NDB

N = [(110) x (220/60)] / 10 = 40 NM from NDB.

Even though these equations are simple, a table would reduce cockpit work load. Headings for such a table (spread sheet) should be "Time flown off-course", "time to NDB", & "Distance from DB",

4.7.4.4 ADF Fix by Timing Without Homing

The above equations apply if crossing an NDB radial. Assume a known ground track. When NDB is approximately abeam of the plane, turn 90° as above, but use distance from NDB to confirm or shift track line. Use mean radial (RB) value to establish progress along course, & thus a fix.

4.7.4.4 Instrument Approaches With ADF

The Instrument Approach System (number 28) includes one that involves only the ADF. Several other approaches use the ADF as an important support component. All instrument approaches are fascinating, somewhat complex, & accomplish a pleasant & vital final portion of a flight that involves inclement weather.

4.7.4.4.1 The ADF is important for intersection identification for several types of instrument approaches.

4.7.4.4.2 The ADF is critical to precisely identify critical points on the final stages of some instrument approaches.

4.7.4.4.3 The ADF approach uses the NDB as the only means of determining critical points & ground track on instrument approaches. Dual OMNI is quite common, & considered nearly essential for IFR flight, but dial ADF is rare. Thus it is difficult to monitor 2 NDB radials for a pure ADF approach. It would require tracking (homing) long enough to establish the correct heading; then checking cross radials when close to that critical intersection (fix). This is essential. So is proper tracking of the inbound radial.

4.7.4.5 NDB Frequency & Useful Range

Although NDBs could be received on any RF band frequency, the most popular & practical, considering the FCC limits & merits of each, is the LF band.

LF radio waves are useful well beyond the line of sight. Conversely, VHF is purely line-of-sight, per Figure 26. The VHF OMNI then has a reception range of only 39 miles if cruising at 1,000' AGL (above ground level), or 125 miles at 10,000'. LF reception range is limited only by signal strength (transmitter power) & meteorological conditions.

Most Aero Nav. radio beacons transmit on frequencies between 200 and 400 KHz. The Narco 31A ADF used by the author is typical of ADFs, & tunable in 3 overlapping bands; 190 - 430, 420 - 850, & 840 - 1750 KHz. A portion of these are the standard AM radio broadcast band; useful for listening to programs like Paul Harvey, as the author did while commuting across Houston for years. It is also useful in locating obscure parts of the country that have standard broadcasting stations or even special purpose transmitters.

Fig D-9 illustrates the various frequency bands & corresponding wavelengths. Frequency is obviously the reciprocal of wavelength.

Ideally the antenna mast length should be 1 / 4 of the wave length, for maximum signal strength. Shorter masts are useful at lower signal strength, preferably with multiples of 1/4 wave; such as 1/64 of wave length. Since the accepted low frequency band is 30 to 300 KHZ, the wave length is 3,250 to 32,500 ft. and such an enormous length is not possible. There are electronic methods of operating with shorter antenna masts.

<u>4.8 Aero Navigation System No. 8:</u> Low Frequency Four Course A-N Range

4.8.1 Background

In September 1929, Army Lt. Jimmy Doolittle was the first pilot to demonstrate that an aircraft could be flown from take-off to landing without ground reference. He used only instruments in his plane & the **<u>new four-course radio range</u>** for course & location, & the radio marker beacons to establish distance from the runway. These permitted him to take off, fly a predetermined course, and land. Primitive DG & AG (gyros) provided attitude & directional guidance, an altimeter provided altitude, and the Low Frequency A-N Range provided positional information.

In 1929 the Federal Aeronautics Branch began installing a four-course radio range that permitted pilots flying VFR to listen to audio signals to maintain their course on an airway. Jimmy Doolittle's IFR demonstration led to serious IFR flight using the four course range; particularly for the airlines.

By Dec 1934 the Federal Aeronautics Branch had 68 communications stations on which pilots could request weather updates & navigation assistance by two-way radio. This technology literally revolutionized Aero Nav. It was not only standard for civil air navigation, but the best Aero Nav system available until a decade after WW II.

Both the in-flight com & the LF Radio Range were revolutionary for that time in history.

IFR cross country Aero Nav & flight finally became a reality; possible, but not yet simple, easy, & totally reliable.

Morse code signals consisting of the "A" & "N" were transmitted in alternating quadrants; roughly 90° per segment. The "A" & "N" were opposing; dot & dash; long & short tones. "A" = dot - dash, & "N" dash - dot. The "A" & "N" tones blended into a monotone since the dot & dash of 1 exactly filled he spaces between the other character. When the pilot drifted off centerline, either deliberately or accidently, the short null between signals permitted identification so it would be possible to know whether the dot or dash was the leading code.

Two concepts were seriously considered for a means of indicating airway tracking. The military pilots preferred an audio signal such as on the A-N Range. Airmail pilots, who flew longer distances, objected to a "boring" audio tone, so preferred a visual indicator. In the mid 1950s the consensus by pilots in general, & manufacturers, adopted the visual. Thus the "Visual Omni Range", or VOR, became the dominant & most practical & accurate Aero Nav system for many years. The ease of intermittently observing the OMNI CDI while flying a VOR vs. listening to the continuous tone seems like an obvious good choice.

The last airway light beacon from the system begun in the 1920s was actually not decommissioned until 1973.

Many of the procedures & components of the A-N Range remain. Some are still valued.

4.8.2 Theory

The basic concept of the A-N Range is the directional transmitting capability & the use of the Morse Code to discriminate between the 4 quadrants that result. See Fig 48 for the general layout of signals transmitted by the LF Range station. Note that the transmitted signals are coded with the Morse Code for the letter "A" in 2 opposing quadrants, & with the letter "N" on the adjacent quadrants. The transmission was not limited to 90°, so airways could cross at any desired angle. Fig 49 further clarifies the circular radiation pattern of both the "A" & "N" quadrants.

4.8.3 Accuracy

The steady tone region was 3° wide; which results in a 3 mile width at 60 miles. That means, of course, 1.5 miles off centerline at 60 miles. When 6 miles from the transmitter, 0.15 miles is nearly 800 ft. At 1 mile from the transmitter, the half width was130'. Near the fan marker both axes are quite accurate; possibly as little as 50' realistically, depending on altitude, since the fan marker beam expands with altitude increase.

A degrading factor is the interpretation of the A-N null. It depended on the pilot's ear, & his perception of the tone. This was much more difficult with static induced electrical interference that is so common for AM radio in the vicinity of thunderstorms. Storms could degrade signals to the point of becoming unusable.

4.8.4 Application

The LF Range only provided a LOP, so if IFR the only way that GS & positional information was gleaned was with station passage; the cone of silence.

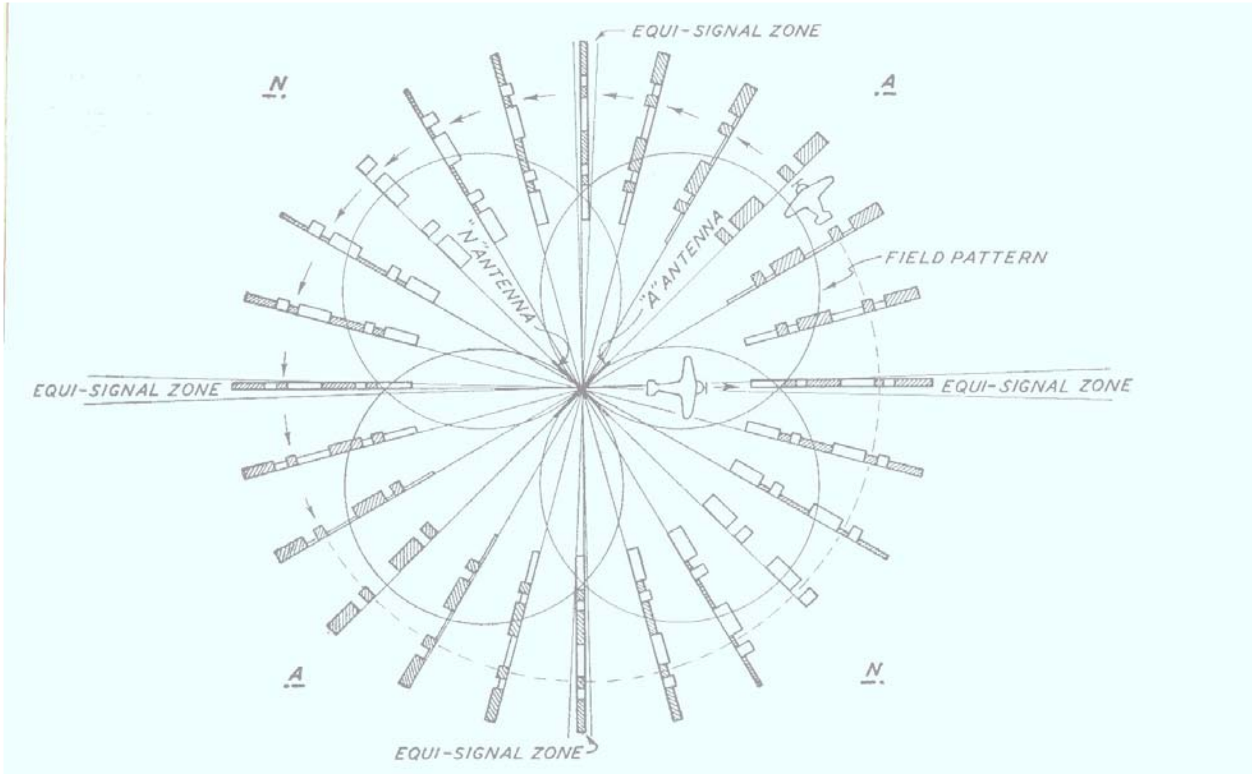

Fig 48: General Layout of Signals Transmitted by an A-N Range Station.

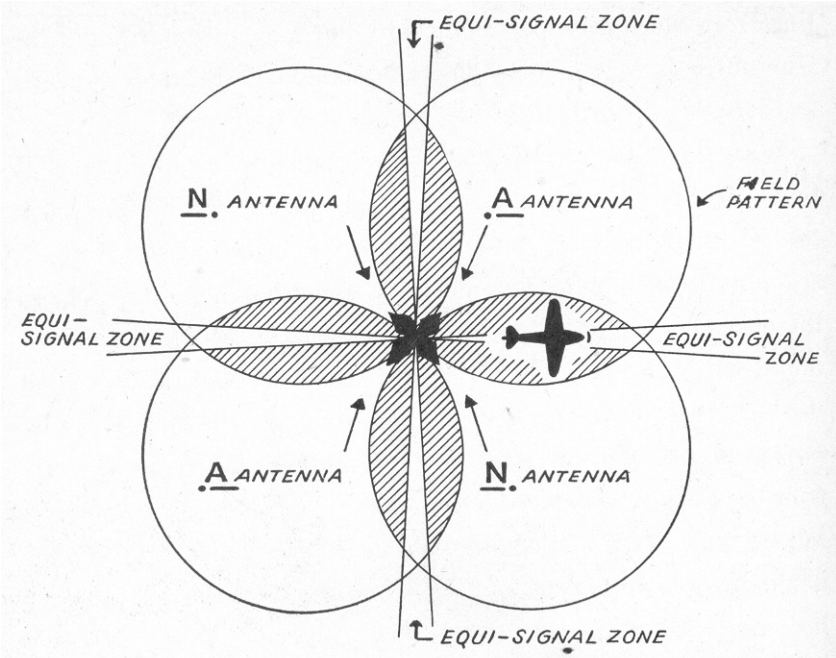

Fig 49: Circular Transmitted A & N with Overlap for Steady Tone

A part of the functionality of an Aero Nav system is the actual fix; for progress along the course. Not even direction from the transmitter could be instantly determined. There was nothing to indicate whether the plane was heading toward or away from the station. The pilot could leave the audio volume at an optimum position & carefully determine volume change as the signal faded when distance increased; or became louder when distance decreased. This took time & was certainly neither precise quantitative.

The pilot flying the four-course radio range airway consulted his chart to find which letter he should hear to fly the right side of his chosen airway. He then adjusted his course until that letter was slightly detectable. It was safer to fly a short distance to the right side of a course to minimize the risk of a mid air collision with oncoming traffic. The "A" or "N" permitted pilots to know his lateral direction off airway; but not the magnitude of the offset. He simply listened to the Morse code audio signals to distinguish which quadrant he was in. If he was on-course (on the airway centerline) the "A" & "N" tones blended into a monotone.

Without a chart the pilot had no way of knowing which side of the airway he was on; or which way to deviate to move closer to the centerline of the airway. The possible logic of always having the "A" on the left did not apply since the "A" was on the left only when flying 1 direction; not the reverse. An aviation chart (Sectional or WAC) indicated which side each was on in any given location. The chart also provided MC, frequency, MEA, MOC, MRA, etc. One of the beauties of the A-N radio range was that the pilot could fly precisely on the airway centerline, or preferably just far enough off the centerline to clear oncoming traffic, in case an oncoming plane was at the incorrect altitude. Offset was possible, but not quantitative. Distance off centerline varied with each pilot. The "A" would be a little stronger than the "N"; or vice versa when slightly to the side of the airway centerline. When the plane was directly over the main antenna, as stated in Aero Nav system No. 7, the pilots received no signal. That cone-of-silence; or Cone Marker, or Z marker, gave a positive fix. It was ambiguous, though, in the event of static, & there was also a risk of lack of pilot attention. An indication of station passage.

The airway A-N Range system was identified using colors rather than the current numbering system.

LF Range transmitters were located along the airways, spaced closely enough to assure adequate signals over the entire airway system. Some transmitters & fan markers were located near airports, because they were necessary for the essential, complex instrument approach system, as described in Aero Nav system number 30.

The instrument approaches, especially, were very demanding. A circling approach was often required to complete the landing. The low-frequency range approach required that the pilot follow a very difficult procedure that was a genuine indication of, & proof of pilot proficiency in instrument flying. A frequently expressed comment was that it "separated the men from the boys".

The A-N radio range, was the primary Aero Nav system used by aircraft for instrument flying, including instrument approaches, from 1930 to the mid 1950s. It was considered safe, accurate, & reliable, regardless of its drawbacks & susceptibility to electrical storms.

When a plane needed to change course to follow a crossing airway, a large radius turn was unavoidable. A "procedure turn" was required if high precision was necessary. More likely, they would simply begin the turn upon reaching the cone of silence. The pilot then blended onto the new course; & turned slightly after the final intercept to maintain the new heading.

Wind correction was necessary to "kill drift". Drift could be determined experimentally, so knowledge of the actual W/V was not essential. Having drift, GS, & TAS the pilot could compute actual W/V. Knowledge of the W/V could be applied to predict what the drift would be after turning to the new course. He could thus immediately turn correctly to the new heading with wind induced drift compensation, upon reaching the null point. This simple set of W/V related computations permitted turning quickly to the new heading for the crossing course, & reduce the time to establish his position on the airway.

The dark area at the intersection of all 4 radials on Fig 48 indicates a cone of silence; where the transmitted signal is not audible. This cone of silence afforded a positive fix, which represented quite an advance at the time. The more modern OMNI provides a more positive fix.

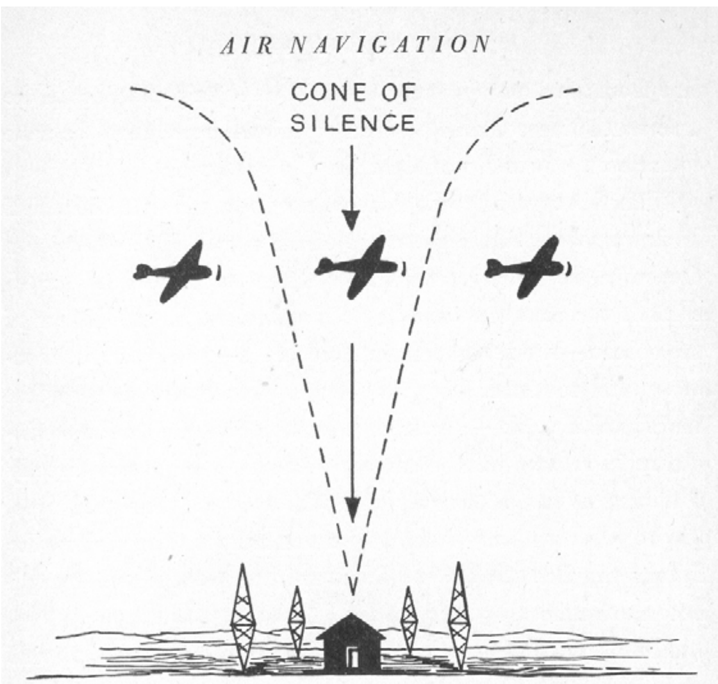

Fig 50: A-N Cone of Silence

4.9 Aero Navigation System No. 9: Marker Beacon

4.9.1 Background

The LF Radio Range described in Aero Nav system No. 8 provided a fix at only 1 low accuracy point in space over the RF transmitter. It did not fully facilitate the position for instrument approaches in particular. The cone-of-silence was somewhat ambiguous. Since pilots deliberately flew to the right of the airway centerline, there was a possibility that the plane would be too far to the side to positively detect the cone-of-silence. There was no other means of determining station passage, so it could lead to serious doubts about position & thus GS.

The fan marker was developed to provide a LF RF beam that was wide enough to intercept most airway traffic, & long enough to provide a more accurate crossing time than the cone-of-silence provided. It radiated upward in an expanding pattern. Its projected dimensions were approximately 2,500' length along the airway of at a point 1,000' above the antenna. Width across the airway was approximately 4,000'. It was located several miles from the LF Radio Range transmitter. These are illustrated in Fig 51.

A variant of the fan marker is called a dogbone; actually closer in plan form of 2 intersecting-faired circular patterns. A more common fan marker is a circular radiation plan form.

A fan marker proved to be especially valuable for instrument approaches. It positively identified 3 points during the crossing, but also aided in providing multiple points for an instrument approach. The value of this is discussed in Aero Nav system No. 30; Instrument Approaches.

Eventually additional marker beacons were added to expand the usefulness & information for instrument approaches. Outer Marker, Middle Marker, & Inner Marker (called FAF; final approach fix). Some operate in the MHz frequency band.

The outer marker is the FAF, & is between 3 & 7 miles from the runway threshold; touchdown point. The middle marker is much the same, but is located between 0.5 & 3 NM from the runway threshold.

4.9.2 Theory

The basic concept of the marker beacon is a sharp pointed oval vertical transmitted radio frequency beam that expands with altitude. Positioned at critical points along an airway it provided information such as the point to start a procedure turn for an instrument approach, or onto a crossing airway.

4.9.3 Accuracy

As he approached the transmitter, the fan markers provided more easily timed exact position information. If the mid length of the beam is carefully interpreted, passage can be determined within approximately 400 feet. Thus an accurate

GS can be computed.

The beam width of a marker beacon is sufficient to be detected when a moderate distance to the side of an airway centerline.

4.9.4 Application

The fan marker was the first marker beacon applied & served very well to improve the capability of the A-N Range. It was especially helpful for instrument approaches. It not only reduced the effort required, but also the risk of misinterpreting station passage.

When a change of course was necessary to follow a crossing airway, a large radius turn was unavoidable. An "overshoot" was inevitable, so a turn through a larger angle, to bring it back to the desired course, would be required. The turn beyond the nominal angle had to be limited to allow a gradual blend onto the course. If however, the overturn placed the plane on the left side of the new airway, the result had to be coordinated by ATC to preclude the risk of a mid-air collision. A "procedure turn" was required in some cases. in either case it required merging onto the new course as quickly as reasonable, but abrupt turns needed to be voided. The fan marker facilitated this complex operation, & reduced risk & even confusion in the cockpit. The fan marker was certainly a major improvement.

Later high precision instrument approaches took advantage of the fan marker & added other types. The improved marker beacons permitted much higher precision approaches to become routine. Most of these marker beacons are expected to be in use for many years.

Conventional marker beacons were used for ADF (NDB) approaches, & later, OMNI, & other high precision approaches, including the ILS.

The ADF & OMNI are also often used as a marker beacons. Both provide a long LOP, but when crossing a precision approach guidance system such as the main OMNI radial or an ILS, they identify a fix.

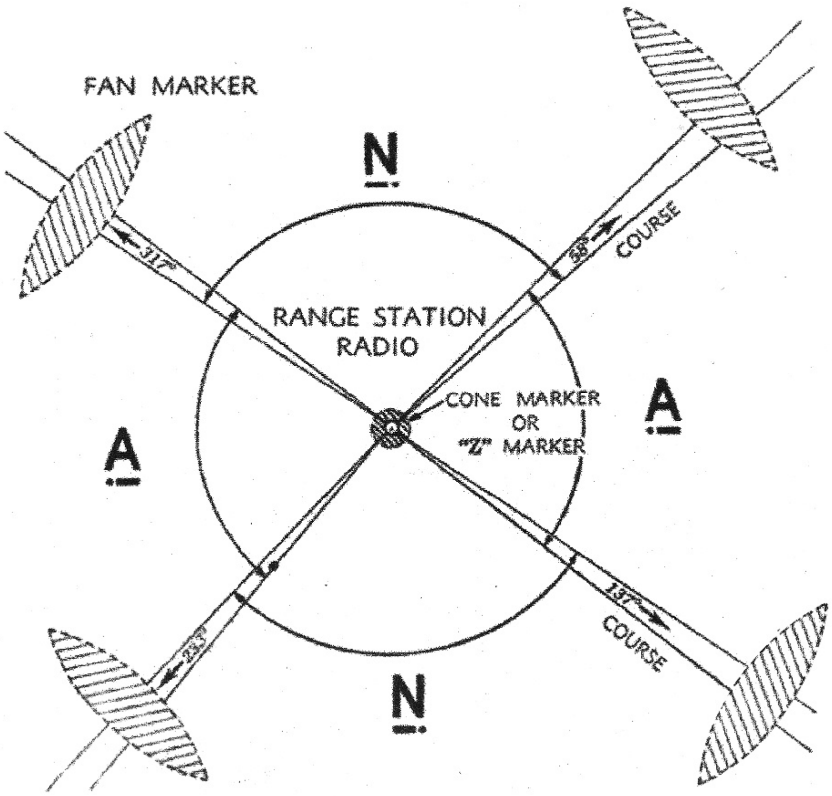

Fig 51: Marker Beacons with A-N Range Transmitter.

APPENDICES

APPENDIX A: Definition of Aero Navigation & Other Relevant Terms

Abeam: 90° relative bearing from the plane. When a VOR, NDB, fix, or any other object is directly to left or right of the plane it is said to be "abeam" of the aircraft.

Accuracy: The degree of closeness of a measured or calculated quantity to its actual (true) value. Also see “precision” & “resolution”.

AD: FAA Airworthy Directive: A mandate to require certified aircraft to have replacement, repair, or inspections of components that “seem to have caused a risk”. Degree of risk determines expediency of action; e.g., "Inspect within 1 year" to" immediate grounding until repair or replacement is completed".

ADF (Automatic Direction Finder): A radio frequency receiver that includes a solid state unambiguous “loop” to positively indicate the bearing from the aircraft to the station (generally a Navigation aid; though it can be a standard broadcast A.M. radio station). Successor of the loop that was manually rotated for optimum signal strength to point to or from a station. Aero Navigators needed sufficiently accurate position info to know whether it was pointing to or from the station. Display is very similar to that shown in Fig. D6

Aerobatics: Stunts such as loops & rolls.

Aero Navigation: Aerial Navigation. The process of determining the position of an aircraft at many points along its flight path, & using the information gleaned from this record to predict important values, such as wind velocity, ground speed, drift angle, ETA, heading to destination, current track, track or course from current position to destination. See brief description of each aero Navigation system covered below.

AG; Attitude gyro. An instrument that includes a simulated horizon that is always aligned with the actual horizon by use of a gyro. Used to facilitate IFR flight.

Agonic Line: A line connecting points of zero magnetic variation.

Aircraft Equipment List : An "aircraft equipment list" is not just a casual expression, but a "formal list of all avionics", including anything resembling avionics & instruments in a plane. If an item malfunctions, that item should be marked as INOP on the equipment List.

Airspeed: Aircraft speed through the air.

Airworthy: A plane in safe & legal flying condition.

ALS: Approach Light System.

Altitude; Absolute: Altitude of an aircraft above the point on the earth directly below the aircraft.

Altitude; Celestial: Angular distance from the celestial horizon to the center of a celestial "entity" (star or planet) measured on a vertical plane that passes thru the earth's equator & the celestial "entity" (sun, star or planet).

Altitude; Indicated; as read on altimeter.

Altitude; Intercept: Celestial altitude of LOP

Altitude; MSL (Mean Sea Level): Altitude above MSL Given in indicated & true altitude; & standard & pressure altitude.

AMEL; Aircraft Multi Engine Land: A rating.

AMES; Aircraft Multi Engine Sea: a rating.

Angle of Attack: The angle of attack is the angle between the "relative wind" & the mean chord line of the airfoil. The mean chord line of the airfoil is based on the stagnation point on the leading edge to the sharp trailing edge of the wing. The stagnation point is the point along the leading edge curvature of a wing where the oncoming air separates into upward or downward flow

Angle of Incidence: Angle of Incidence is the angle between the longitudinal centerline of the aircraft & the mean chord centerline. The mean chord line of the airfoil is based on the stagnation point on the leading edge to the sharp trailing edge of the wing. The angle of incidence is commonly pitched up; as though in a shallow climb.

AOPA: Aircraft Owners & Pilot's Assn: The premier pilot's organization. Without the AOPA the feds & a few unfriendly airlines would certainly have nearly eliminated freedom of flight for private pilots & much of the rest of Genav. Cooperates with EAA frequently.

Artificial Horizon: A gyro stabilized instrument for IFR flying. Also called an AG (attitude gyro): It includes a simulated horizon that is always aligned with the actual horizon by use of a gyro. Used to facilitate IFR flight. Described in detail in the fascinating (some would say exciting) IFR Approach system in this Aero Navigation series.

Attitude gyro; AG: An instrument that includes a simulated horizon that is always aligned with the actual horizon by use of a gyro. Used to facilitate IFR flight. Described in detail in the fascinating (some would say exciting) IFR Approach system in this Aero Navigation series.

ASEL; Aircraft Single Engine Land: a rating.

ASES; Aircraft Single Engine Sea: a rating.

ASR: Airport Surveillance Radar.

Astronomical Triangle: A Triangle on the celestial sphere bounded by the vertical & hour circles through a celestial "entity" & the Aero Navigator's celestial meridian.

ATC: Air Traffic Control: ATC is operated by the FAA to advise & control all aircraft that fly in any type of controlled airspace. This includes assuring specified safe separation from other aircraft, assisting in minor or major emergencies, etc.

ATP: Airline Transport Pilot: A license (rating) that allows a pilot to carry passengers on commercial airliners.

Axis: The earth's axis is the diameter about which the earth rotates.
The celestial Axis is the extended earth's Axis; representing the apparent celestial axis.
An axis of any great circle of the earth is also a diameter of the earth.

Azimuth: The angle measured from true or magnetic North to the position of a plane in reference to a NAVIGATION Aid such as a radio beacon or a VOR (ONMI station).
The angle measured from the North (if observer is in the Northern hemisphere) branch of the Aero Navigator's position to the vertical circle that passes thru a celestial "entity". It is measured toward the East if the body is rising; or West if it is setting.

Bearing: Angular direction of 1 object relative to another; measured in a clockwise direction; thru 360°:
"Magnetic bearing" is measured from magnetic North.
"Relative bearing" is measured from the longitudinal centerline of the plane.
"True bearing" is measured from true North.

BFR; Biannual Flight Review: A mandatory flight proficiency check by a CFI is required of every licensed pilot every 2 years. It is important that each pilot demonstrate proficiency & freedom from "bad habits".

Bullet-Proof: A popular expression used to indicate failure proof; exceptionally reliable

Certified: An aircraft or equipment for same must be certified for full operational use. In '08, a Sportplane category was accepted after years of lobbying by the most prestigious aviation organizations; AOPA & EAA. The Sportplane, experimental, & ultralights must meet specific requirements, but are not certified.

Cardinal Points: The points on a compass rose indicating 0° (360°), 90°, 180°, 270°.

CAS: means calibrated airspeed.

CAT II: Category II high precision "low minimum" IFR approach...

CAVU: Ceiling & visibility unlimited; a common acronym seldom used except in the fabulous Southwestern U.S.

CDI: Course Deviation Indicator: Vertical needle indicates angular displacement from the predetermined, intended radial. Used for OMNI, LORAN, & other Aero Navigation systems.

Celestial Sphere: a hypothetical sphere having a radius of infinity & a center & axis coincident with that of the earth.

Center: A major flight control operation for controlling flight; especially in IFR conditions.

CFI: Certified Flight Instructor: A person who has been trained in pilot training from 1st flight to any & all ratings (except the below).

CFII: Certified Flight Instructor, Instrument: A person who has been trained in pilot training involving an Instrument Rating & ATP. A CFI is qualified to train pilots in rudimentary emergency only type Instrument flying.

CG: Center of gravity.

Circle of Equal Altitude: An imaginary circle on the surface of the earth that is a projection from any heavenly "entity" representing a specific altitude angle. It passes directly over the Aero Navigator's position. A celestial sighting taken from any point along this circle will read the same elevation or celestial altitude. The observers on opposite sides of this circle may be within a few miles of one another, if the elevation is near 90°; or hundreds or thousands of miles if the altitude / elevation is a low angle.

Clearance delivery: A station in Center that reads IFR clearance to pilots just before departure; usually by radio while on the ramp.

Collimation: In celestial terms (not optical) this is placing the celestial "entity" into coincidence with the sextant reference bubble.

Commercial License: An advanced FAA certificate (beyond Private License) that permits "flying for hire"; under some conditions carrying passengers for hire.

Compass Heading or Course: Actual reading of compass; after accounting for magnetic influences within a plane.

Compass Card: A small card posted near the magnetic compass in any plane to indicate the correction for magnetic deviation. See Table in D.R. Navigation in this introductory course.

Course; Compass: The intended compass direction of the aircraft "track" along the ground; direction that the compass will point.

Course; magnetic: The intended direction of the aircraft "track" along the ground with reference to the magnetic North pole.

Course; True: The intended direction of the aircraft "track" along the ground with reference to the true North pole.

Crab: Drift correction for crosswind. For landing a plane the favored method of preventing drift upon touchdown is to lower 1 wing & apply rudder opposite to the bank angle, resulting in cross control & out-of-trim condition (ball off center) to align the longitudinal axis of the plane with the runway. This permits landing on 1 main gear that is perfectly aligned with runway centerline to avoid skidding on the runway & risk of loss of control after touchdown. An alternative method is to hold wings level with proper drift angle (crab angle) until an instant before touchdown; then depress the rudder to kick plane straight with the runway the instant before touchdown. This method is more susceptible to error & out of alignment landing. Given a very high crosswind component there is an increased risk of loss of control upon touchdown.

Crab Angle: Used in flight to stay on desired course in flight. Turning slightly into the wind to correct for drift. Determining crab angle is a definite Aero Nav function.

Cross Country (Flight): Any flight that departs one airport with the intention of landing at another airport. Generally involving the use of 1 or more Aero Navigation Systems.

CS or CSP: Constant speed prop; Pitch automatically adjusts as aircraft throttle or pitch attitude are changed to maintain any desired RPM

Dead Reckoning: Aero Navigation based on mathematical manipulation of known values; air speed, heading, wind velocity, wind velocity induced drift, distance to be traveled, & time required for the flight.

Declination: The arc of the hour circle measured from the equinoctial to the celestial "entity". Measured North or South through 90°.

Density Altitude: Pressure altitude corrected for non standard temperature. At standard conditions pressure & density altitude are the same.

Deviation: Deviation results from assorted EMI or other magnetic disturbances within the pane.

DG; Directional Gyro: A "compass" that has no magnetic sensing capability. It must be set to heading value by referring to the magnetic compass. Responds instantly & correctly to turns, unlike the magnetic compass. Shown in Fig. D6

DH: Decision Height for IFR Approach.

Dip; Celestial: Apparent lowering of the horizon as aircraft altitude increases. A correction must be applied if a Nautical Celestial Sextant is used in aircraft. A bubble type sextant is thus preferred for Celestial Navigation aboard aircraft.

Dip; Compass: As the proximity to the North Pole decreases the North magnetic pole vertical component increases; thus pulling down on the North pole of an aircraft compass.

Direction Finder: A radio frequency receiver that includes the bearing from the aircraft to a radio station (generally a Navigation aid; though it can be a standard broadcast A.M. radio station).

Disoriented: Flying casually, & making a series of random angle turns, without regard for compass heading, can easily lead to disorientation; having no "feel" for the heading. A common occurrence that is easily cured by noting the old reliable magnetic compass. This often results in being lost, but knowing heading usually aids in reorientation.

DME; Distance Measuring Equipment: A variant of the VOR - OMNI Range that adds distance to station; unfortunately it is "slant" range, so is biased as horizontal distance from the station decreases. Similar to TACAN.

Downdraft: Naturally occurring downward movement of air that tends to cause loss of altitude.

Drift: A Cross Wind will drift an aircraft off course; expressed in miles or angle. A simple trigonometric relationship.

Drift Correction: An angular drift correction for wind induced drift will permit an aircraft to remain on course.

E-6B: The E-6B was developed in the early days of Aero Navigation & is called a "computer" even though 1 side is a multi scaled rotary slide rule, & the back side is an ingenious "wind vector" tool.

EAA: Experimental Aircraft Assn: The organization that grew out of the desire of individuals to design, build & fly planes without the usual lengthy & costly certification process. The EAA was overwhelmingly successful. Responsible for support of some of the greatest aircraft designers of all time; such as Burt Rutan. Responsible for support of some of the greatest aircraft material developers; materials that were soon adopted by virtually all military & airline aircraft manufacturers. Indirectly responsible for development of some of the finest planes ever flown. Cooperates with AOPA frequently.

Ecliptic: The path of the sun as it appears to rotate around the earth.

ELT: Emergency Locator Transmitter: A g-force activated radio beacon that transmits on the emergency frequency until turned off or battery capacity is fully consumed. Many aircraft monitor the emergency (121.5) frequency. They report it & attempt to determine its location. Downed planes are likely to be found quickly; usually soon enough to rescue the injured. The ELT can also be manually activated in the event of a successful emergency landing that would not trip the g-switch.

EMI: Electro-magnetic Influences: most electronic & electrical devices emit EMI.

Empennage: The tail surfaces of an airplane; usually a vertical fin (stabilizer) & horizontal stabilizer (both fixed in place) & movable control surfaces; rudder & elevator. For yaw & pitch stabilization and control.

Empty: Weights: empty= max gross, payload = passenger & baggage weight allowance, useful = max gross less empty weight.

Equator: The only Great Circle on the earth that shares its axis as its diameter. The earth axis is coincident with the equator axis.

Equinoctial: The earth's equator projected onto the celestial sphere.

Equinox, Autumnal: Intersection of the Equinoctial & the Ecliptic as the sun reverses direction & begins "move" to the South

Equinox, Vernal: Intersection of the equinoctial & the ecliptic as the sun "moves" North

Equipment List : An “aircraft equipment list” is not just a casual expression, but a “formal list of all avionics”, including anything resembling avionics & instruments. If an item malfunctions, that item should be marked as INOP on the equipment List.

FAA: Federal Aviation Administration; the U.S. governing body for all civilian aviation.

FAF; Final Approach Fix for instrument approaches.

FAR: Federal Aviation Regulations (federal rules under which flight operations are conducted)

FBO: Fixed base operator, a facility that offers fuel, hangar, tie-down, & mechanical services for plane owners. Usually also offer CFIs & planes for flying students for most or all licenses & ratings; & BFRs.

FG: Fixed landing gear as opposed to RG; retractable gear.

Fix: An absolute position on the face of the earth used in Aero Navigation. Visually observing an “identifiable” point on the earth provides a “fix”. 2 or more LOPs cross at a point to provide a “fix”. Most Aero Navigation systems provide a fix “directly” at a specific point; or on many points. A “fix” is often used in Aero Navigation to compute distance traveled, ground speed, wind velocity (speed & direction), drift, a new track & heading, & an ETA.

Flare: Pitching up to slow a plane while reducing the sink rate immediately before touchdown.

FM: Fan Marker for IFR approach. Fascinating; see Approach, IFR system in this Aero Navigation series.

. FPP or FP: Fixed pitch prop

FSS: Flight Service; provides aviation information & communicates same to pilots. A major contact for General Aviation both in the air & on the ground (except in dealing with tower controlled airports).

Fuselage: The “body” of an airplane.

General Aviation: Private users whose main purpose in flying is for personal business, pleasure, & corporate use (executive travel, product deliveries, technical services, sales travel, & much more).

Geodesic: A segment of a great circle drawn on the earth.

Glider Rating: Authority to fly a glider; actually, usually a sailplane; a high performance glider.

Global Positioning System: A phenomenal satellite based electronic Aero Navigation system that grew into much broader use by hikers, campers, drivers, sailors, & even police & industry. It is capable of providing exceptionally precise & accurate continuous position info as long as the antenna is not electronically shielded from satellite reception. The GPS also provides ground speed, track, & even altitude (MSL). It has an internal data base that has thousands of points identified for use by pilots & aerial Navigators; virtually everything a pilot has use for. It does not, of course, eliminate the need for other Aero Navigation systems.

GS: Glide Slope for ILS approach. A major component of the most used precision ILS landing system. Described in detail in the IFR Approach system in this Aero Navigation series.

Gross: Weights: empty= max gross, payload = passenger & baggage weight allowance, useful = max gross less empty weight.

Ground Effect: Operation within 1/2 wing span of the ground increases lift because the air deflecting off of the ground impinges on the lower side of the wing to add additional lifting force.

Ground Speed: True speed in relation to the earth’s surface; speed across the earth. True airspeed corrected for wind velocity.

Gyro Compass: Directional Gyro: A “compass” that has no magnetic sensing capability. It must be set to heading value by referring to the magnetic compass. Responds instantly & correctly to turns, unlike the magnetic compass. Display shown in Fig. D7 is very similar.

Hand Held: The expression “hand held” in this Aero Navigation course refers to specific independent portable avionics devices; but only OMNI based Nav-Coms or GPS units that are now commonplace among Gen-Av pilots.

Heading: Compass: The direction the aircraft is “heading”, or “pointing”, as indicated by the aircraft compass.

Heading; Magnetic: The direction the aircraft is “heading”, or “pointing”, with respect to the magnetic North Pole.
Heading; True: The direction of the aircraft “heading”, or “pointing”, with reference to the True North Pole.

Homing or "Home in on": Following a radio beam to its transmitter of origin. As in the homing pigeon.

Horizon; Apparent Haze: The earth horizon appears to drop in relation to the aircraft as visibility or haze increases. Quite logical since the curvature of the earth is the dominant factor in establishing the apparent level of the horizon only in places like New Mexico where 100 mile visibility is the norm.

Horizon; Apparent True: The earth horizon appears to drop in relation to the aircraft at altitude increases.

Horizon; Attitude: The “Artificial Horizon” instrument which is also known as an “attitude gyro” or “gyro horizon” intended to replicate the earth horizon to permit flying without outside reference; in IFR instrument meteorological conditions. It contains a movable illustration of the “earth & sky” that retains the relationship between the true & indicated horizon as the aircraft pitches or rolls to keep the pilot informed of the aircraft attitude when engulfed in clouds..

Horizon; Celestial: The Great Circle on the celestial sphere that is tangent to the earth’s surface at the point of the plane position.

Horizontal Situation Indicator: HSI per below definition:

Hour Angle; Greenwich: Arc of the equinoctial measured from the Greenwich meridian to the hour circle passing thru the celestial “entity”, over West 360°.

Hour Angle; Local: A term of interest to celestial navigation. An arc of the equinoctial measured from the aircraft position meridian (upper branch) to the hour circle passing thru a celestial “entity”; over West thru 360°.

Hour Circle: A Great Circle on the celestial sphere passing thru both poles & a celestial “entity”.

HSI: Horizontal Situation Indicator: A single aircraft instrument that combines several vital functions to simplify flying; especially IFR, & reduce pilot work load. It is an expanded function DG. Typically it includes the directional gyro, but it is usually slaved to a remote compass & connected to a VOR & glide slope needle. Permits flying an IFR approach with reference primarily to the HSI; only 6 primary flight instruments. Not true in the case of back course approach.

IAS: Indicated airspeed.

IFR: Instrument Flight Rules: A term used to describe flying in IMC (instrument meteorological conditions); or without visual contact with the terrain below. FAA rules under which pilots must operate in method.

ILS: Instrument Landing System: An exceptionally high precision & capable 2 needle landing system using OMNI in conjunction with a separate glide slope receiver. The OMNI uses an adjacent frequency, & is tuned as usual using the OMNI, & simultaneously selects the glide slope receiver. The OMNI CDI vertical needle indicates lateral displacement from the runway centerline. The horizontal needle indicates vertical displacement from the glide slope angle; normally 3°. There is an important ambiguity that must be understood. Considerably lower ceiling minimums than most other Instrument landing systems.

Inner Marker: A marker beacon for use in instrument approaches.

Instrument Rating: An advanced FAA “rating” that permits operating in IMC (instrument meteorological conditions; below FAA minimums for visibility &/or ceiling; typically in clouds).

Isogonic line: A line connecting points of equal magnetic variation.

Kill Drift: Correct for wind drift by crabbing into the wind to cancel out drift.

Knot: A unit of speed having a value of 1 nautical mile per hour.

KTS or kts: Abbreviation of nautical miles per hour.

Latitude: Angular distance from the equator; North or South; 0 – 90°; stated with N or S after the number.

LF: Low frequency; a radio band covering the 190 to 300 KHz range.

LDA: Localizer-type Directional Aid.

LFR*: L*ow-Frequency Radio Range.

Light Twin: A twin engined plane that is much the same as a single engined plane, & is powered by similar sized engines. Two passenger light twins are rare; most are 4 to 6 place; a few are a little larger.

Line of Position (LOP): See LOP below.

LMM: compass locator at middle marker for instrument approach.

LOC: ILS localizer for instrument approach.

LOM: Compass locator at outer marker for instrument approach. ILS Outer Marker. Used to facilitate IFR flight. Described in detail in the IFR Approach system in this Aero Navigation series.

LOP (Line of Position): Celestial: An arc representing a single celestial “entity” altitude or elevation angle as measured using a sextant or AstroCompass for the purpose of Aerial Navigation by celestial. The observer knows he was on that line at the “instant” recorded. Although an arc, it is for practical purposes a straight line except when a celestial “entity” is observed at an extremely large altitude (elevation).

LOP (Line of Position): A single line upon which the plane is or was on at the “instant” recorded. This line may have been obtained by any of several means, including VOR, NDB, or even map reading.

Longitude: The distance, in degrees, from the meridian that passes thru Greenwich England. The Greenwich meridian is known as the prime meridian because it is the reference for both longitude & time. Longitude is given in angles from 0 to 180°; either East or West of the Greenwich meridian. GMT is Greenwich mean time, so time all over the world is established from GMT. Eastern Standard time is 5 hours earlier than GMT; Central 6 hours, etc. Each index mark on a Sectional chart represents one nautical mile only at the equator, but not at higher latitude parallels; always 1 minute of longitude. As latitude increases, the distance represented by an arc-minute decreases.

LORAN: Long Range Navigation system that offers wide coverage & excellent accuracy.

Lost: Obvious, but easily solved by use of any of several available Aero Navigation systems.

LSA; Light Sport Aircraft: A relatively new category of aircraft that will still take 2 people cross country at twice the average speed of a car, but with limitations that include hp, speed, gross weight, & weather conditions; & daytime only.

Magnetic Compass: As used in Aero Navigation the magnetic compass uses a 360° scale, with bold cardinal points minor divisions; mounted to a conical frustum which is rotated by the magnetic field of the earth. Shown in Fig 8.

Magnetic Heading or Course: Heading or course after correction for magnetic variation.

Magnetic Variation: See Variation; Magnetic.

Manifold Pressure: Engine Manifold Pressure.

Map: Normal definition is used for map.

Meridian (Celestial): A projection of the earth meridians upon the celestial sphere.

Meridian (Earth): A great circle that passes through both poles (true earth axis; not magnetic poles). For globes & maps meridians are typically drawn every 30°. A line of either latitude or longitude is shown on Sectionals every 30 arc-minutes; 2 per degree. There is 1 index mark per mile (1 per minute) & 60 marks per degree of longitude. The earth has a circumference of 21,600 nautical miles at the equator; 24,873 statute miles.

Meridian (Prime): The meridian that passes thru Greenwich England establishes the reference for both time & longitude. Longitude is given in angles from 0 to 180°; either East or West. This prime meridian the reference for time. GMT is the acronym for Greenwich mean time, upon which the remaining time zones receive their reference.

MDA: Minimum Descent Altitude.

MEA: Minimum Enroute IFR Altitude.

MM: ILS Middle Marker. Precision middle marker to identify a critical point on instrument approaches. Used to facilitate IFR flight. Described in detail in the IFR Approach system in this Aero Navigation series.

MOCA: Minimum Obstruction Clearance Altitude.

MP: Short for engine Manifold Pressure.

MRA: Minimum Reception Altitude.

MSL: Mean Sea Level.
Nadir: The point on the earth where the observer is positioned. The nadir is directly below the zenith, which is directly on the celestial sphere.

Nautical Mile: A distance represented by 1 arc-minute on any great circle on the earth. Thus always 1 minute of latitude, but one minute of longitude is 1 NM only at the equator. 6080 ft.

Navigation Aid: A device or system that allows pilots to access some form of Aero Navigation info; generally a visual or electronic “beacon” or the equivalent that is located at a fixed point along the face of the earth. It may provide a positive fix, or simply a LOP.

Navigation-Com: The primary Aero Navigation system from the mid 1950s to the early 2000s; still a vital part of most Aero Navigation systems for Gen-Av. As “normally” understood a Navigation-Com consists of a permanent aircraft mounted OMNI VHF receiver that is most often mounted in the same panel unit as a VHF simplex transceiver (transmitter integral with receiver that transmits & receives on the same frequency; to greatly relieve pilot workload & reduce risk of improper settings). Nav-Coms typically receive all 200 channels of the OMNI band, & transmit & receive on all 720 VHF Com channels. GPS manufacturers started adding com transceivers to some units to alter the original Navigation-Com dominance. Some original Navigation-Com designs were reconfigured as hand held units in the late 1990s, for redundancy & use in Ultralights & other sporty aircraft. A smaller number of frequencies is commonplace in these hand held Nav-Coms. These look more like the older walkie-talkies & are typically in a 1 to 2” thick package that is not radically larger than a hand held Engineering calculator. Unless otherwise noted, in this Aero Navigation course series, Navigation-Com refers to an OMNI based navigation receiver with transceiver as described above.

Navigation Tool: A device that aids in the use of charts or navigation aids, & is used in preflight planning & or in flight to assist a pilot in determining pertinent information about his ground speed, fuel remaining, route, his position, drift, or some other information of value to him in flight.

NDB (ADF) means nondirectional beacon (automatic direction finder).

NDB; Non Directional Beacon or Non Directional Bearing: NDB-Beacon is a radio transmitter that may be tracked/ homed in on using an ADF; NDB-Bearing is the bearing indicated by an ADF or equivalent to provide a LOP or to permit flying directly to the beacon that the bearing is derived from.

NOTAM: Notices to Airmen; Regularly updated NOTAMs advise of virtually all potential unpublished hazards or changes at all facilities including airports & navigation aids. An example might be that a specific runway at a named airport is closed for repairs.

NWS: National Weather Service

OAT; Outside air temperature; required for TAS computations using the E-6B

Octant: An instrument that is, for practical purposes, a less capable predecessor of the sextant; designed to measure the elevation (also called altitude in celestial navigation) of a celestial “entity” for the purpose of establishing observer position (a Fix) or a LOP.

OMNI: A high frequency radio signal that is received from a VOR (Visual Omni Range) transmitter. The transmitted signal consists of 2 overlapping oscillating signals that are out of phase with one another for the purpose of providing an unambiguous signal which provides an angular position from the VOR station zero reference which is magnetic North.

OM: ILS outer marker. Outer marker for instrument approaches. ILS Outer Marker. Used to facilitate IFR flight. Described in detail in the IFR Approach system in this Aero Navigation course.

Over Square: Manifold Pressure larger than hundreds of RPM. A common misconception that remains even though experts disavow it & Lindbergh positively proved it wrong during WWII & saved many lives as a result.

PAR: Precision approach radar.

Parallel of Latitude: Any great circle above & parallel with the equator. Treated much like meridians for the purpose of chart making & Aero Navigation. Distance along a parallel is stated in degrees & arc-minutes, but as latitude increases, an arc-minute represents progressively shorter distances; unlike 1 arc-minute = 1 nautical mile as with meridians.

Payload; Weights: Payload = max gross - empty weight - fuel load; Payload = the passenger & baggage load. Empty weight will decrease as avionics are added.

PIC; Pilot in Command: The person responsible for all actions & decisions on a flight. A CFI is always the PIC unless simply a passenger. Two fully qualified pilots can exchange the position of PIC at will; as if making a trip together. Sully, in “Miracle on the Hudson” was PIC, but could have handed that responsibility over o the co-pilot until the emergency occurred. Had he done so, a quick “I’ve got it” or the equivalent would have instantly made him PIC the instant a bird strike occurred.

Pilotage: Navigation by reference to objects on the ground; an old fashioned name for map reading.

PIREPS: Pilot Reports in flight; the FAA solicits in-flight reports of any potentially dangerous activity or event noted during a flight. This could include forest fires, severe turbulence, heavy smoke, icing conditions at pilot’s fight altitude, or a simple W/V change or deviation from forecast values. PIREPS are normally given by radio immediately to the nearest FSS or other FAA facility.

PIREPS: Pilot Reports by pilots who flew & evaluated specific panes to document strong & weak points; AOPA prints & offers to members who have an interest in a specific plane.

Pole; Celestial: Projections of the N & S poles of the earth.

Pole; Earth: N & S ends of the axis of the earth.

Polar Distance: Arc of the hour circle. This is equal to 90° minus the declination of the celestial “entity”. Distance between celestial pole & the “entity”.

Precision**:** Also called reproducibility or repeatability. Also see “accuracy” & “resolution”.

Pressure Altitude: The altitude indicated when the altimeter setting is set to standard value of 29.92” Hg; or standard pressure at sea level corrected for a temperature of 59°F. At standard conditions pressure & density altitude are the same.

Range: The max distance a plane may fly with a normal fuel load. “Range” generally assumes a “safe” fuel reserve. IFR flight requires enough reserve to fly to the destination, shoot a missed approach, fly to the approved / legal alternate airport, & land with a 45 minute fuel reserve. VFR flight requires a 30 minute reserve during the day or 45 minute at night, but the author is not the only one who considers such short reserve inadequate.

RB: Relative bearing; angle off nose of a plane in most applications.

RBN: Radio Beacon. An extremely valuable radio nav aid that is used for many purposes. Fascinating discussions give in depth info on uses in IFR Approach system in this Aero Navigation course series.

Resolution: Minor (small) units of division as opposed to major divisions. Also see “precision & “accuracy”.

RG: Retractable landing gear.

Rhumb Line: A straight line drawn on the Mercator or Lambert chart crosses Meridians at a constant angle. If a flight is to be above the equator, & the course is not directly North or South, the flight path should cross meridians at varying angles. A straight line on these 2 charts is thus not a Great Circle, nor is it the shortest distance between departure & destination points. A Rhumb Line is also longer than a Great Circle.

RVR: Runway Visual Range as measured in the touchdown zone. Still is, & will remain in statute miles.

SBS: Side By Side seating.

Scratch (or scratch built): Building an Experimental (homebuilt) plane from plans or the builder’s own design. Not a kit.

SE: Single Engined plane

Sextant: A term used for any optical instrument capable of measuring elevation (elevation is called altitude in celestial applications) of an object; in this case a celestial “entity”. Capable of measuring up to 120° above the horizon. An octant is virtually the same except elevation is limited to 90°.

Shoot Landings: A term that means repeating the T.O. - landing cycle for proficiency or for the joy of landing the plane, without stopping. For some proficiency requirements the plane must fully stop; generally requiring, for safety, exiting the runway & making a 180° turn to return to the departure end of the runway.

Simplex: Transmitting & receiving a communication radio on the same frequency. Generally tuned by 2 coaxial knobs; one for coarse, & the other for fine tuning. An example would be 122.80 where the 122 is tuned by the larger knob closest to the face of the unit, & the 0.10 is tuned by the smaller knob.

Sky Vault: An imaginary hemispherical “cover” over any point on the face of the earth. The visible portion of the celestial sphere.

Slope Thermals: Updrafts generated by wind driven air flowing up a slope, such as a mountain. Capable of inducing high rate of climb on most lightplanes, & supporting sailplanes for extended periods of time.

SMOH: Since major overhaul; engine. Typical Continental & Lycoming engines last 2,000 hours; & then may be overhauled.

Solstice: The point of max declination of the sun relative to the Earth. Summer solstice is North of the equator. Winter solstice is South of the equator.

Stagnation Point: The stagnation point is the point along the leading edge curvature of a wing where the oncoming air separates into upward or downward flow.

Statute Mile: An arbitrary unit of measure based on 5,280 ft. Used as aircraft distance & speed unit of measure until the NWS forced the issue by reporting wind speed in knots.

STOH: Since top overhaul, engine. Typical Continental & Lycoming engines last 600 to 2,000 hours before a top overhaul is necessary. Cost is moderate vs. a major overhaul.

Sweep: The passage of an object by a rotating Radar beam.

T&B: Short for Turn & Bank. See fig D-3

TACAN; Tactical Air Navigation: An ultra-high frequency military improvement (accuracy) over the civilian DME system.

Tandem Seating: 1 in front of other.

TB: True bearing; measured from true North

Time; Apparent: Actual local time established by sun at its zenith.

Time; Civil (also called Mean): Time established by the passage of the mean sun as it moves along its path.

Time; GMT (Greenwich Mean Time): Time established by the passage of the sun as it passes the Greenwich meridian. The Greenwich meridian is known as the "Prime Meridian" because it is the international reference for both longitude & time. Longitude is given in angles from 0 to 180°; either East or West of the Greenwich meridian. GMT is Greenwich mean time, so time all over the world is established from GMT. Eastern standard time is 5 hours earlier than GMT; central 6 hours, etc. GMT is not impacted by daylight savings Time. All official aviation reporting is in GMT. This simplifies long range jet traffic in particular.

Time; Sidereal: Time established by a star at its zenith.

Time; Solar: Same as Apparent.

TO: Short for Taking off in an airplane.

Track; Compass: Actual path across ground referenced to compass; with deviation correction.
Track; Magnetic: Actual path across ground referenced to compass; with variation correction.
Track; True: Actual path across ground referenced to true North.

Transceiver: A radio frequency transmitter with a receiver that is linked for simplex; both operate on the selected frequency. Virtually all Aero Navigation utilizing communications involves a transceiver since the introduction of all except the earliest OMNI systems until the GPS took over some of the com function in a similar manner. Modern OMNIs were nearly all "1-1/2" systems until this later GPS adaptation. By "1-1/2" is meant a transceiver (communication transmitter-receiver) with an integral OMNI receiver. The OMNI frequency band is adjacent to the com. transceiver band; the 2 bands are tuned separately. The handheld Navigation-Com (OMNI & transceiver) is one example of an item that is pilot-owned, & also of the "1-1/2" system.

True Airspeed: Airspeed corrected for altitude & temperature; technically also for instrument (calibration) error.

True Altitude: Altitude above MSL.

Turn & Bank. The only gyro instrument in the primary panel. See fig D-3

Turn Coordinator: A less informative & useful primary panel gyro that sometimes replaces the T&B. See fig D-3.

"Turn Inside of": Turning in front of a plane on final approach, which is normally forbidden, & simply unwise. The author once turned into the largest gap he found with possibly 50 planes on final at a very large fly-in breakfast. He & his best friend saw several planes damaged that day, as pilots braked in front of a plane, turned too close in front of a landing plane, & even when a military trainer had the brake grab & ground looped; with a wing tip skimming across top of an Eurcoupe canopy. No injuries. Later that day, this 100 hour (at that time) pilot dropped below the power lines after crossing them on takeoff, & kept it much too low for several miles just to be sure to avoid the other departing traffic.

Tx-Rx: Short for transceiver; a unit that transmits & receives on the same frequency (simplex); simultaneously tuned.

Updrafts: Upward flowing air; generated by wind driven air flowing up a slope, thermal activity within cumulous or even cumulonimbus clouds. Some are generated by air passing over warm surfaces on ground, such as from water to plowed ground. The sole source of support for sailplanes; some even permit flying all day for hundreds of miles.

Useful; Weight: Max gross minus empty weight = Useful load. Payload = Max gross minus empty weight minus fuel load. Payload = Passenger & baggage weight allowance. Empty weight will decrease as avionics are added.

Utility: The utility of a plane is a combination of performance & characteristics. A reputable Genav organization developed an equation that weighed things like payload vs. gross weight, stall vs. cruise speed, stability, & range. When they first developed the rating the Cessna 172 had the highest rating. For a particular pilot's desires, or needs, or for a particular type of flying needs, the rating may not be true. They may prefer a Beech Bonanza, Mooney M20, Cessna 206, a J3 Cub, or even a Pitts aerobatic biplane.

Variation; magnetic: The difference between the reading of an error free magnetic compass & true North. The magnetic North Pole is displaced from the true North Pole so compasses do not normally point to true North; but to magnetic North. This combines with extraneous magnetic influences (such as iron ore deposits) to prevent a perfect compass from reading true North. These 2 influences are not independently distinguishable by either the pilot or the compass, so they are combined in what is called " magnetic variation". At any point on the earth & any moment in time the magnetic variation is fixed. It actually does change over a period of time. Magnetic variation is indicated on the aviation charts, & must be accounted for in the process of Aero Navigation.

Vector; Wind: See Wind Vector.

Velocity: Speed-direction vector.

Vernier: A vernier is a long scale adjacent to a measuring scale, on which the 2 extremes align with at the 2 extremes of the actual measuring scale. Generally linear, as with calipers; & sometimes found on circular (angles) scales. The vernier scale has 1 more minor division than the actual scale. Thus if the zero index is shifted typically 1 mil (0.001") past the initial point of alignment, the second minor division is properly aligned, & the interpreted new reading is then 1 mil larger than the initial reading. As the scale is shifted 1 mil larger & the adjacent minor division will be aligned. Each advance will progressively increase readings, until the zero index is eventually the properly aligned minor division. The author once had access to a 3 ft tall height gage that had an unusually long glass vernier. Glass was used for the vernier because of its lower coefficient of expansion. It was actually possible to read this height to within 1 mil from arms length.

Vertical Card magnetic Compass. Remote compass, gyro stabilized compass, ADF, & D.G. all have very similar display to that shown in Fig. D7

VFR means visual flight rules.

VHF means very high frequency. Most modern navcoms operate in the VHF frequency band.

Vertical Card Compass: A true magnetic compass, except that the face is similar to the DG shown in Fig. D7 The vertical card compass is unique in that it is nearly immune to the dip error of the conventional conical frustum type compass, so follows the aircraft heading more precisely.

VOR (Visual Omni Range; VOR means very high frequency omnirange): A high frequency radio transmitter that transmits 2 overlapping oscillating signals which are out of phase with 1 another. The signals are interpreted by a panel mounted (generally) radio receiver to provide an unambiguous signal which depends on the angular position from the OMNI station zero reference, which is magnetic North. The transmitter station is called a VOR. The airborne receiver is called an OMNI.

Waypoint: A point of interest that is pre programmed by GPS or LORAN manufacturer; generally from the FAA Airway system data base, or by the Aero Navigator. The latter may be points of interest such as a beach or a pasture that he lands on occasionally.

Weights: empty, max gross, payload = passenger & baggage weight allowance, useful = max gross less empty weight.

Wind Vector: The "Wind Vector" involves 3 vectors; W / V, air speed & ground speed vectors. Typical of engineering applications, vectors can be solved graphically (on a sheet of paper) or with a computer; or in the case of the wind vector, the graphical side of the old but ingenious E-6B.

W / V; acronym for wind velocity: Wind direction & speed; the typical engineering definition of velocity.

Vertical Circle: A great circle on the celestial sphere that passes thru zenith, nadir & a celestial "entity".

XC; Cross Country Flight: A common Aero Navigation short hand in written & spoken communication.

Zenith: The point on the celestial sphere directly above the observer.

APPENDIX B: Safety

B.a. Safety of Lightplanes; General Considerations:

The reader might ask, "How safe, practical, & complex is it to fly & navigate a lightplane?"

Any properly trained pilot who remains proficient through practice & / or training can be as safe as he wants to be. A pilot may not legally operate a plane that is unsafe, nor can he fly if for any reason he is unsafe. Actually, it is surprisingly easy to obtain & maintain a Private license, which insures adequate proficiency & training to fly safely & avoid unsafe operation & conditions. The Private license includes Aero Navigation, as well as flying an airplane. Even flying without ground reference is perfectly safe as long as he has obtained the necessary training, & passed a written exam & a flight check. The instrument rating assures that he is safe. IFR flying is safe, practical, easy, & very beneficial, as long as a pilot maintains proficiency with frequent practice. IFR obviously requires an intimate knowledge of Aero Navigation. The instrument rating does add utility to flying. It measurably reduces weather cancellations & trip interruptions or delays. The FAA specifies the required training & continuing practice & training re several FAA licenses & ratings; all of which require Aero Navigation.

Modern American Gen-Av is indisputably, inherently very safe; in fact, the safest of any in the world.

Engines are always a point of concern for the non flying public. Their concern is based on lack of information. Dual ignition systems (magnetos) are the rule. A magneto failure is extremely rare, but when it does occur, the plane can fly indefinitely on 1 magneto. The author can only recall having one uneventful in-flight magneto failure in 4,600 hours of flying.

Continental & Lycoming Engines are the most reliable ever manufactured; & power most certified & most homebuilt lightplanes.

American made certified lightplanes are the safest & most capable made, & have dominated the world market since soon after the brilliant Wright brothers mastered flight.

Most engineers have had too many unpleasant experiences with assorted inferior Japanese products to trust Honda & Subaru; especially on a plane. A standing rule by some equipment manufacturers is that Japanese products be avoided, but if they must be used, reduced to less than half the rate load or strength; often 25%. The author recently developed & directed a long term operation of an extremely precise & thorough small industrial engine testing program. All engines were pushed well beyond max rated power, & at max rpm, when possible. Output power & rpm were precisely measured. All were run until worn out, if practical. Onan was not included; but an 18 hp Onan was known to be excellent; used on the beautiful little 100 mpg Quickie homebuilt planes.
1. Briggs & Stratton produced 100% of rated power from dozens of engines. None ever failed; all lasted 1,000 hours or longer.

2. The Kohler always produced 110% of rated power; some ran for over 1,000 hours; most past 1,500 hours, until simply removed to make room for other engines.
3. Fuji built Wisconsin Robin engines could produce 100% of rated power, but had serious metallic particles by 100 hours or less.
4. The highly touted Honda industrial series engines were a different matter. The distributor admitted that they would only produce 90% of rated power, but in fact, it was impossible to achieve over 60%. Worse, they were worn out at, believe it or not, 5 hours at max possible power; & at max obtainable rpm. Since they were obviously not satisfactory, & actually were the most expensive engine tested, in terms of dollars per rated hp, Honda testing ceased after 25 engines were worn out. The Honda distributor was heavily involved in trying to determine the reason for such poor performance. No success. Obviously other Honda users must operate at very low power & rpm.

Unlike drivers, who receive absolutely no training on how to handle emergencies, such as skids, pilots do receive such training. Every pilot receives hands-on training on how to correctly respond to nearly every type of emergency. He should periodically practice these on his own, or with a CFI. He must demonstrate flight proficiency every 2 years at his mandatory BFR (biannual flight review) Poor performance during a BFR does not result in grounding; only additional training to meet FAA standards; during the BFR.

Modern American made Aero Navigation systems are the best quality & most reliable in the world, & offer the greatest ease of operation & best accuracy. Many countries do not provide some of the navigation aids that the pilots in the U.S. consider necessary. Mexico, for example, has very few VOR stations, & Aero Navigation there is inconvenient in much of the country. Their rules of flight are antiquated & very limiting; especially backwards for SE lightplanes.

Light twin airplanes have a very good safety record, but actually not as good as single engine lightplanes. One reason is that some pilots do not maintain the high level of proficiency required to properly accommodate engine loss. It is even more difficult than one would expect to determine which engine failed. Quick proper response is essential; especially at low altitude, at night, or under IFR conditions. With 2 engines the chance of engine failure is obviously doubled.

FAA certification should assure a safe design, but on very rare occasions an unsafe plane is certified. It is doubtful that there was ever a lightplane or large commercial aircraft manufactured that has no AD notes. The main thing is that most AD notes result before catastrophic failures or performance issues resulted in fatalities. The Piper Comanche light twin is one that nearly lost its certification. The author once seriously considered the SE version of the Comanche, but was actually advised against it by the Piper dealer; possibly because he had only 450 hours logged, & his pilot-wife had only 60 hours at that time. Another factor was his claim that mufflers must be replaced every few years. His original Cessna mufflers were weld repaired once in 41 years. Another exception to the value of airworthiness of a plane was the Mooney-Mitsubishi MU-2, which was designed & made in Japan. It was more difficult to fly than many military planes, & much less safe than any other certified light twin. The MU-2, like many military trainers, requires constant attention to keep it flying. The military trainers were justified in such instability in that that wanted to keep a pilot "on his toes" to better enable them for the rigors of combat flying. Also stability reduces maneuverability, & thus combat performance. Because of the exceptionally high accident rate, the FAA began action to remove the MU-2 certification. They eventually allowed it to keep the cert, but only with elaborate, extensive special training of pilots. The author has only known one MU-2 pilot who felt safe in it, or liked flying it, & that was only because it kept him sharp; no room for error.

The author has lost only 3 friends to light plane crashes over the years (a minute fraction of his losses to car accidents), but the daughter of a close friend was the only one killed because of an unsafe design; in an MU-2, along with her husband. Both had a great deal of time at the controls of & were well qualified to fly the MU-2. The plane also suffered from exceptionally high maintenance cost & time. The entire Mooney product line is otherwise well known & very highly respected as an exceptionally efficient, & well built plane. The 4 passenger planes are exceptional, but the tiny single place Mooney Mite powered by a 65 hp engine is truly a joy to fly.

Redundancy is also very important. Most pilots avoid flying IFR with a single Navigation Com. It is inconvenient, but also risky since a Navcom could fail, even though they are exceptionally reliable. Nor would he consider flying IFR without a series of redundant features to allow safe flying in the event of multiple failures.

As the author "preached" over the years in engineering, as well as in flying, lack of "redundancy" has the potential of causing a disaster. He inadvertently proved this in a case of unexpected 40,000 psi spikes from unpredicted sonic flow caused by millisecond cycle times for specially designed valves. Spikes destroyed 5,000 psi pressure gages & 20,000 psi transducers in a 3,000 psi hydraulic system. Since then he has convinced many engineers & even the NBBI (National Board of Boiler & Pressure Vessel Inspectors) that dual gages would protect against operation or testing with a seriously out of calibration pressure gage. Likewise, in aircraft safety issues, redundancy is worthy of very serious consideration. Despite the exceptional reliability of modern avionics, failures do occur, so redundancy is justified. Dual OMNI is the norm, & facilitates operation with on-track & cross track monitoring. Simultaneous dual function is especially helpful during IFR operations. Regarding redundancy, most pilots avoid flying IFR with a single Navcom. It is inconvenient, but also risky since a Navcom could fail, even though they are exceptionally reliable. Prudent pilots would not consider flying IFR without a series of redundant features to allow safe flying in the event of multiple failures.

If flying a twin he certainly would not attempt to take off with only 1 engine running, although an eye witness reported that a DC-3 did just that on a South American jungle airstrip; insane. Loss of an engine in a twin engined plane causes serious yaw, which must be overpowered by the rudder. But rudder has sufficient power only at moderate speeds; well above stall speed. That demands that both lift-off & landing approach speeds be well above stall speed, so inherently increases risk of injury in case of loss of control. Higher speeds are necessary because below VMC (minimum controllable SE speed) the only way the plane can be flown is with all power reduced severely. This essential safety rule was violated by operators of a large Mexican commercial multiengine plane that operated out of a runway that was definitely too short. They “mushed” off well below VMC & struggled to clear the trees at the end of the runway. That commercial flight would not have been permitted in the U.S., nor would any safety conscious rational American pilot have flown it, with or without paying passengers.

There is, however, a great risk of losing control if the pilot does not frequently practice SE (single engine) operation. For safety, that is actually accomplished with 1 engine throttled back, & that prop set for neutral (zero) thrust; for the appearance of operation on 1 engine. In the event of an actual engine failure, the other engine can safely be brought into operation immediately. If practical the pilot might consider periodic proficiency training at a flight simulator training center. Modern flight simulators are so very realistic that pilots, when given multiple emergencies, have actually experienced heart attacks. The simulator instructor typically add multiple emergencies, until even the best pilot is unable to handle them all. It “separates the men from the boys”, as the saying goes. Instructors can assure a pilot that he is competent; or suggest further training. Such serious emergency training in the air would indeed be hazardous. In fact a 4 engined jet crashed in New Orleans simulating an engine out emergency. The FAA examiner pulled both engines on 1 side to minimum power; the cockpit recorder indicated that the pilot had pleaded with him to restore power. The FAA examiner & flight crew perished, along with a few in the homes that the plane crashed into. Soon after that flight simulators became so sophisticated that they replaced actual aircraft for such hazardous training. Such sophisticated flight simulators are not generally necessary for lightplanes, but simpler ones are still very useful. For IFR they must, however, be certified for IFR, & supervised by a CFII in order to be logged as simulated IFR flight. Some very good home computer type flight simulators may be good for proficiency & practice, but most do not meet legal simulator standards.

The FAA & most American airlines have stringent safety requirements, as do Ausies, Canadians, Brits, South Africans, Scandinavians, & most Europeans. Many other countries allow many practices that would not be allowed in the U.S. Pilot qualifications are also quite stringent in the U.S. There have been many frightening stories told (& some experienced by the author) about a variety of foreign airlines. China is actually building an airplane for airline use that will offer “standing room only”. Some airliners from South of the border do land in the U.S. with some passengers standing. They must not, however, depart the U.S. with unsecured passengers. One irrational passenger refused to keep his safety belt fastened on an airliner. When it crashed his body became a missile that killed 8 people who were seated in front of him. A powerful argument for the obvious; standing should be prohibited in an airliner. It points out the idiocy of allowing children to ride in school busses without seat belts. Likewise, trains & highway busses have an excessive fatality rate because they do not mandate seat belts.

B.b. Passenger-Co-Pilots

Occasionally lightplane passengers obtain the “Pinch Hitter” training that was developed by the AOPA for the purpose of learning enough to locate an airport & land safely in the event of pilot incapacitation. In 2008 a low time Cessna 172 pilot successfully did just that in a King Air after the pilot passed away at the controls. A Beechcraft King Air is a very sophisticated turboprop twin, but in fairness, it is quite a “straight forward” plane. Hindering the 172 pilot is the fact that most SE Private pilots have absolutely no idea how to manipulate power controls in a sophisticated turboprop twin; not even text book training. Any CFI, or even a plane owner, can train a frequent passenger to safely handle such emergencies. The author was once thrilled to be given the opportunity to be sole manipulator of controls of a King Air from New Orleans to the West side of Houston in a company plane.

Aero Navigation is critical to flight safety in all cases. Aero Navigation errors are nearly all “Pilot Error” and should be called “Aero Navigator” error. Aero Navigation errors are the most frequent cause of fuel exhaustion, which causes most off-field (emergency) landings. Emergency landings are not necessarily hazardous. It depends on the terrain, & obstructions; but mostly on pilot proficiency & ability to remain calm. The urge, if in doubt of ability to make it to a suitable emergency landing site, is to ease back to “stretch the glide”. If gliding, as he should be, at best glide speed, he is already stretching his glide. Easing back on the stick or wheel will actually shorten the gliding distance. As usual, he should fly by the book; including gliding at the IAS that the manual says to maintain.

B.c. Safety is in the hands of a Pilot-Aero Navigator.

A pilot’s safety is not in the hands of those irresponsible law breakers such as DUI / DWIs, junkies, car-jackers, illegal aliens, large poorly maintained Mexican trucks, or criminals trying to evade police. These are responsible for an enormous number of vehicular deaths & injuries literally every day in the U.S.; but virtually never responsible for any injuries or deaths involving aircraft. Most Americans have lost an acquaintance to a DWI or an illegal alien. As the author was writing this PDH course he heard on the news that 4 separate police chases occurred in less than 24 hours in a small portion of North Dallas, TX. At least 2 of these involved several separate very serious accidents; if one could call them anything less than attempted murder.

Pilots are not at risk by such “criminals” because it is essentially statistically impossible for these reprobates to, even if they were flying, endanger other pilots. They could be spotted by alert pilots, & monitored by the FAA, so that all pilots in the vicinity could be alerted, & diverted away from them. The Aero Navigation capability would facilitate these warnings, if such an improbable event ever did occur. The airspace is nearly infinite in volume.

Although there are “airways”, there are no “absolute highways” that limit 2 dimensional space available to planes. Add to that the availability of an infinitely large number of altitudes, & there is virtually no limit to the number of aircraft that can be simultaneously flown. A published analysis once reported that if every plane in the U.S. were to fly at the same time & altitude over just 1 state (Arizona), each plane would have 1 square mile to itself. An application of this rationale is illustrated by comparing the U.S. with the British IFR control systems. IFR flying in the U.S. is absolutely under positive control (& observation), with specified minimum vertical & horizontal aircraft & obstruction clearance. The Brits, for many years simply “assumed” that if 2 planes were headed for the same airport while engulfed in clouds, they would never actually be at the same point at the same time; thus no mid-air collision. They actually had no mid air collisions as a result of this approach. Mid-air plane accidents are literally fewer than 1 in a million.

B.d. FWI (flying under the influence):

An exorbitant percentage of auto accidents are the result of DWIs (DUI). Not so with flying under the influence; FWI (or FUI). In fact, like driving, FWI is not only hazardous, but also shows a serious lack of common sense. An added risk in FWI is the fact that the detrimental effects of high blood alcohol content increases as altitude increases. This is indicated in Appendix F, the Standard Atmosphere table, Fig F1. At approx 7,500’ altitude the atmosphere is down to 75% of that at sea level, so the oxygen level is also at 75% of normal. At 18,000’ only half of the atmosphere remains. It seems logical that FWI at altitude would be even worse than “hedge hopping” (skimming along near the ground), which, of course, is unsafe even for a highly skilled, sober pilot.

One scientifically conducted series of tests proved the seriousness of flying while under the influence. The results may shock a few. Two physicians, who were also competent pilots, received FAA approval to conduct tests at a major airport, using a diverse assortment of pilots as “guinea pigs”. They monitored blood alcohol content continuously, & slowly increased that from very little alcohol to fully intoxicated. The most impressive test was when a highly experienced commuter airline pilot was directed to make an instrument approach. The hood blocked all outside reference, but he was exceptionally competent at flying instrument approaches, having routinely flown more approaches under IFR conditions every day than most pilots fly in a month. Very few airline pilots fly as many approaches in actual IFR conditions, because he flew only on the East coast where ceiling & visibility are among the worst in the U.S. The typical instrument approach requires flying about 10 miles in a straight line while descending at a very precise rate. This true professional only intercepted the glideslope one time; when he crossed it 90° off his heading. Obviously he would have crashed; probably miles from his intended touchdown point, had he been the PIC, as was the norm for him.

B.e. Flying vs. Driving:

For the author’s most frequent routine flight there is a major <u>safety</u> advantage that may not be obvious between flying & driving; avoiding the “drug lords” & other illegal aliens, & car jackings when driving near the Mexican border; though it seems that illegal aliens are killing Americans in every state, & by every means.

The 3rd dimension actually seems to be an advantage, once a pilot has mastered flying, & IFR is no exception, if he maintains currency; & proficiency. Among hundreds of IFR approaches, with all types available, one particular precision approach stands out. The 2 needle ILS gives precise indication of where the plane is relative of where it should be vertically & laterally as he cruises down the glide path. As he follows the needles down the glide slope the plane should be ideally positioned; at any given distance from the runway there is only 1 small point in space that is correct.
On one recent flight by the author & his wife, the air was so turbulent that the assistance of the safety pilot was almost essential. The plane moved almost violently about all 3 axes. The needles seemed to flop around. As they approached legal minimums, the needles were further from center than on any previous approach. It was not scary, but it certainly was unpleasant. Had it been just a little worse, he would have executed a missed approach, & waited for the turbulent weather to move further from the runway. Upon breaking out at minimum allowable altitude, with needles very far off center, the plane was only a few feet from the runway centerline. Not so bad after all. The ILS is indeed exceptionally precise and safe, even with very low cloud ceilings. The ILS system is based on the VOR-OMNI range system, which was introduced in the early 1950s.

A major portion of fatal car accidents result from "other" irresponsible drivers; less frequently than by their own carelessness. Most airplane crashes are the result of "pilot error". Sometimes that error is in the form of bad judgment, such as flying into extreme weather conditions; or conditions he has not been trained to deal with. Some result from failure to properly maintain proficiency. Inability to properly perform the important function of Aero Navigation is another rare cause, but Gen-Av accidents of any type are certainly rare. Sometimes the pilot is simply not attentive. Engine failures are virtually unheard of, & airframe structural failure is a minute fraction of that. This has been true since the 1930's; & largely since the 1920s, but since the 1940s the FAA certification restrictions have made improvements prohibitively costly. As a result genuine safety improvements have been limited. Nonetheless, they are quite safe.
A person could teach himself to drive a car by initially driving very slowly; preferably in parking lots, but not by starting on a fast freeway, or a racetrack, competing with others at 200 mph. With flying, the first flight requires skilful flight control & throttle manipulation at relatively high speed. Without a CFI (certified flight instructor) in the right seat that flight would almost certainly end in a disaster. That does not mean that it is overly complex; it simply requires special training. Many employment activities do require special training. Even though flying is more complex than driving, it is obviously not beyond the technical skill or capability of most people. The author likes to compare flying with the car, motorcycle, & SCUBA diving. In all 4 cases the initial learning process requires some attention & adaptation. None are inherently "natural", but once the person gains a little skill, they are comfortable performing routine tasks. A person then responds to the lean of a motorcycle automatically. He does not have to think about turning as he approaches a curve in a car. SCUBA & flying actually seem a little more natural in that a person just "thinks" it's time to turn, ascend or descend, & it "seems" to happen automatically. The person cannot "fully master" flying unless he actually becomes "a part of the machine" & the environment; & the machine is a part of him. A pilot must know a few limits, such as stall speed, so he won't pull back too hard or too long on the stick (or wheel), but his air speed instrument indicates changes quickly, & he is quickly alerted of speed changes by the sound of the engine & wind, & the "feel of the stick" (resistance to movement). A motorcyclist & driver also quickly learn that they cannot take a sharp corner at full speed. They learn some "common sense" rules; consciously or unconsciously.

B.f. Insurance Cost vs. Safety

Insurance cost should be an indicator of safety. The author paid three times as much to insure a V6 Camaro that was worth 10% of the value of the family Cessna. In both cases, full coverage. Cars have a higher risk of liability claims & even to a lesser extent, vehicular-airframe damage; compared with Lightplanes. Conversely a major portion of the increased cost of a new plane is product liability insurance. A study of a variety of actual unethical trial cases involving aircraft shows a strong influence of irresponsible, unethical, & simply dishonest legal influences. The new Beechcraft Bonanza was introduced in 1947 at a price under $5,000, vs., $600,000 1985. A fact is that in 1985 a full 66% of the cost of a Bonanza went to pay the product liability portion for that particular plane. Presumably other aircraft manufactures suffer the same fate. The reason for excessive product liability insurance rates for GenAv manufacturers is similar to the medical malpractice rate problem, "out of control, unethical law suits". One extreme but common example was a case where a Cessna 210 crashed because of pilot error. A disreputable lawyer actually convinced the widow & an inept jury that the cause was carburetor ice. She won an illegitimate multimillion dollar settlement. This resulted even after expert witnesses told the jury what any pilot or mechanic in the world could have attested to. The 210 is powered by a fuel injected engine. Injectors do not ice up. There is no possibility that the 210 engine quit, if it quit at all, because of carburetor ice. Even if it had been a carbureted engine, & it did quit because of carburetor ice, that would have been "pilot error", not the fault of Continental or Cessna. Carb ice is a fact of life that must be addressed by each pilot anytime it occurs. A contributing factor would have been a failure on the part of the FAA to demand that instructors teach a proper way to avoid & rid an engine of carb (carburetor) ice. Unethical lawyers & inept juries & judges are the reason that Cessna, Beech, & others must pay exorbitant product liability fees; vastly greater than is justified. The faulty FAA teaching is to apply carb heat any time the engine is idled during fight. This incorrectly taught method often produces insufficient heat from the idling engine exhaust. Many pilots incorrectly overcome this risk by carrying power during approaches. This results in a reduction of the ability to correctly judge gliding distance in the event of a power loss. If the air approaching the venturi is below freezing, it may contain ice crystals. The carb (carburetor) heat will melt these ice crystals which quickly become water droplets, since the carb (carburetor) heater is hot when first applied. The venturi cooling often refreezes the water droplets, which may cause engine failure. The longer it takes for the pilot to recognize that he has carb ice, the cooler the system will be. There is a very high likelihood that the carb heater will no longer melt the ice. The author speaks from experience; that was exactly what happened to him. With 300 hours logged, this Sophomore Mech. Engineering student was practicing for his commercial, which he promised a crop dusting operator he would obtain. He deliberately picked a very difficult to use small plot of farm land for a practice emergency landing, on a very cold windy day. He used carb heat as he was taught; WRONG ! He had to choose between a fence that he was drifting toward, & a very low wing tip because of the severe cross wind. His beloved '48 Cessna 120 needed minor repairs that exceeded his budget. The engine started after a short warm-up. He never again used carb heat "indiscriminately", in 4,600 hours of flying. He did not carry power on approaches to keep the carb heater warm, even on high performance planes such as the Pitts or WWII trainers. Nor did he ever lose an engine even briefly because of carb ice. There were surprisingly few occasions where he used carb heat at all; flying during cold winter weather under IFR conditions over Arkansas may have been the only case of serious icing during cruising flight among many thousands of hours from dry desert air, to 100% humidity, to flight under structural icing accumulation, to snow storms. He did add a carb air temp gage on his 3rd plane, & very rarely saw it in the caution range, in flights all over the U.S. & beyond, in all weather, humidity, & temperatures.

B.g. Engine Failure Results in a "Dead Stick" Landing, but Little Risk to Occupants

Related to the emergency landing, a common misconception is that planes "fall out of the sky" if an engine fails. In fact, most prudent pilots shoot approaches & landings with power reduced to an idle. Thus every time a pilot flies, he is "practicing" for "dead stick landings"; enabling him to maintain good judgment, & the ability to glide to a safe landing, in the extremely rare event of total power loss.

"Dead Stick" is a misnomer, in that the stick is quite active & useful. The author has very rarely applied power during a landing approach; even in very high performance planes. As a result, he keeps his judgment sharp, so nearly always touches down within a few feet of his intended landing spot. A dead engine will not be hazardous, given a suitable landing site that is within gliding distance. The biggest problem then is to correctly estimate absolute altitude above the ground, since it is unlikely to be that shown on the altimeter, nor is it likely to be the same elevation as the departure point. A typical lightplane has a glide ratio over 9:1; meaning it will glide 9 miles from an altitude of 5,000'. Even in hostile mountainous, or congested metropolitan areas, the 255 square mile area that is within gliding distance should afford hundreds of suitable emergency landing sites. This course dispels myths & misconceptions, but also gives advice on how to reduce risk as a passenger.

A tidbit that can prevent an unhappy landing in the event of fuel exhaustion or engine failure is the seemingly improbable fact that a rotating prop has greater drag than a stationary prop. This may not sound logical, but it is a matter of "Disc Area"; not blade area. The total drag of a 2 bladed prop is typically 15 times the blade area. Thus aerodynamic flat plate drag will be 15 times as great if prop is "windmilling".

A "typical" prop blade mean chord is approximately 4" (2.5 tip to 6.5" root max) & overall prop length is 6.5'. Blade area is then near 2.1 sq ft. But disc area is 33.2 sq ft. In the event of a total power loss, once all hope of a restart is lost, it is preferable to slow the plane briefly until the prop stops; then return to "best glide speed" to maximize the glide. It is always possible to "S" turn, add a notch of flaps, or even drop nose with flaps fully extended, to increase sink rate if altitude is too high. It is never acceptable to try to "stretch a glide", because the dead stick glide should always be at the "best angle of glide" speed. At that speed, either reducing or increasing speed will reduce gliding distance.

B.h. The Ultimate Dead Stick Landing

Sailplanes are proof positive that planes do not fall out of the sky without power.

Sailplanes actually ride thermals to stay aloft for long periods of time. Soaring is a serious competitive sport for some pilots, & an excellent way to improve flying skills solely for the pleasure of flying.

A variety of lift sources not only keep sailplanes aloft, but allow for long distance flights. They are discussed in paragraph C.f.a.d.c.

B.i Mid Air Collisions:

Mid air collisions are infinitely rarer than collisions for any other type of vehicles; cars, boats, etc. AirVenture Oshkosh has 10 times the traffic of the busiest airport in the world, & it is common to see 4 planes taking off or landing on the same runway simultaneously. Yet mid-airs very seldom occur even at AirVenture Oshkosh. They are even very rare on the narrow curving Hudson river corridor in NYC. Traffic is extremely heavy there. Yet the Aug 8, '08 mid-air was the first in years. That mid-air was apparently caused, at least in part, by the age old low wing visibility problem. Both high & low wing designs have visibility merits & concerns. The author is uncomfortable with low wing visibility. Some feel the same about high wing. It is obvious that the low wing is very poor for sightseeing; or just enjoying the scenery. The great old biplanes suffer the worst of both.

B.j Safety over Water:

It is always safer to avoid flying over large bodies of water; out of gliding distance from a shoreline, even though engines virtually never fail.

Ditching (landing a land plane in water) is a very uncommon occurrence, but it was always considered logical that a low wing RG was much safer than high wing FG planes. It seemed logical, until someone analyzed all available ditching records & found the opposite to be true. Survival rate was much better in the cases of high wing FG planes.
Even seaplanes do not handle landings well in mid-ocean. The author wanted to be able to fly out into the Gulf of Mexico to SCUBA dive. The FBO who offered a seaplane rating just happened to be 1 of the first SCUBA divers in the Houston area. He advised the author that the moderate sized waves in the Gulf were not really safe for the Lake amphibian he would rent. That ended another great idea, but it motivated him to obtain his seaplane rating, which proved to be a great pleasure. All 4 kids enjoyed it, but not his wife. He did find that a very light chop on a lake could give one quite a jolt.

B.k Wisdom is as Great an Asset as Proficiency

Flying is indeed very safe, but a pilot can never be too careful !!!! Safety infers constant attention to surrounding terrain, including potential emergency landing spots, & surrounding airspace. It also means knowing as much as possible about the plane. Best climb speed for obstruction clearance, best glide speed, routine speeds, emergency procedures, etc should be memorized & practiced. Proper calibration of all instruments is important. This includes fuel gages. An embarrassing story on the author proves that one can never be too careful. He always noted the fuel gage reading before adding fuel, so he would always know just how much fuel remained at each mark on the fuel gage. With his first plane the gages were purely mechanical, so literally fool proof & always precisely in cal. But the later electrical gages were always suspect. On one occasion the author & his wife departed Houston for El Paso & flew VFR at 10,000'. Having just installed new fuel gages, he "assumed" they were in proper calibration. "Bad assumption". He also "knew" that if they flew on both tanks for 2 hours before switching to the left tank, the tanks would not cross feed through the vent, so each tank would contain the same amount of fuel at the time of switching. He "knew" that the fuel for the remainder of the flight should be exactly as he expected, by timing fuel burn. He also "knew" that with the mixture adjusted precisely by use of the EGT his fuel burn would be consistent for the entire flight. So he carefully monitored fuel gage readings vs. computed fuel burn based on time & power setting. He "knew" that the fuel burn rate in each tank would be exactly the same after switching. He knew that if the left tank ran dry 2:30 after switching from "both" to left tank, the right tank "would" have 2:30 of fuel remaining. He knew when he "should" touchdown at El Paso. So he "knew" he'd have 50 minutes of fuel left when he landed at El Paso International Airport. Less than his usual 1 to 2 hour reserve, but quite safe. Many pilots routinely plan on a 1/2 hour reserve, & the FAA recommends a 45 minute reserve for VFR. When his co-pilot-wife repeatedly cautioned him that he had less fuel than he thought, he politely explained why he was right; each time; in detail. "He was rightfully confident". He finally gave in & deviated slightly to pass "near" a small field that she thought he should land at. Having called El Paso Approach Control (not required for VFR) to advise of his descent & ETA, he continued toward El Paso. When the engine suddenly quit at 2,000 ft AGL, he calmly & confidently called El Paso Approach & announced an engine failure, & deviation to another airport that was within gliding distance. Passing over numerous 5 ft high sand dunes did not alarm either, because both knew the airport was within reach. Their heading was already parallel with the runway, & only a short distance to the side. He called on Unicom frequency to alert possible traffic. As he neared the runway he made a short close base leg, then final, & made an uneventful landing on an uphill portion of the runway. He coasted uphill to the ramp, & stopped with negligible braking at the fuel pumps. He knew he was low on fuel, but confident that his wife was still wrong as they asked for help when the FBO walked up. She asked for fuel. He asked for a mechanic. She just happened to be right. The tanks were both dry. A look back on the situation was a lesson well learned; one that certainly could have ended in a disaster; probably a damaged plane; possibly worse. First, the new fuel gages were not in cal. One showed much more fuel than it should have. Second, the fuel burn while on "both tanks" was most likely unsymmetrical. Third, the fuel burn on the last tank was probably considerably higher than on the first. Fourth, a long standing rule for both pilots, & pilots in general, was broken; if conflicting info is evident, always believe the worst. In this case, if 1 pilot thinks a landing is justified, the proper action should have been a premature landing. Had the landing been 1/2 mile shorter, the 5 ft sand dunes would not have added to the pleasure of the flight; to say the least. Flying is indeed very safe, but a pilot just cannot be too careful !!!!

B.l Night Flying

Is night flying another issue? The author actually avoids night flying, because only approximately 10% of the available airports offer lighted runways, & in the extremely rare event of an engine failure, a safe landing would be questionable. If an unexpected fuel stop is necessary, it would be more difficult to find an airport close to the intended course. A more serious issue involves emergency landings. If an engine fails, it is generally impossible to see & avoid obstructions. It is also difficult to find a suitable emergency landing site in the dark. Conversely, in the event of an engine failure under IFR conditions, during the daylight, a pilot would usually have adequate time to find a suitable landing site, upon exiting the bottom of the clouds. Even in the worst of weather, midcourse IFR flight is rarely flown with zero ceiling, or zero visibility, so IFR is considerably safer than night flying in this respect.

Another critical factor in night flying is that clouds are not always visible. Inadvertent cloud penetration requires an immediate transition from VFR to IFR, which many instrument rated pilots consider to be difficult. It would certainly be much more difficult for a pilot who is not instrument rated. One thing that does reduce the risk is the fact that every private pilot is required to receive some IFR training & practice; not enough to safely file & fly an IFR flight, but enough to make a 180° turn safely in the event of an unintentional cloud penetration. Again, a pilot's license really does assure the ability to perform & in fact, enjoy a safe flight.

IFR flight by an instrument rated pilot is quite safe as long as the pilot "maintains proficiency". FAA regs (regulations) require "adequate" proficiency practice & training. BFRs (Biannual Flight Review) confirm adequate proficiency in whatever ratings the pilot holds, every 2 years. Thus to retain the authorization to fly IFR, he must demonstrate IFR proficiency during his BFR. If a flight simulator is too expensive or unavailable, IFR "hood" flying permits practice with a qualified safety pilot in VFR weather. This provides adequate proficiency practice. Actual IFR flight is obviously counted for the proficiency requirements.

B.m. Safety via Reliability:

A few aircraft-engine endurance records prove a critical factor in aircraft safety:

B.m.a Engine Endurance in 1935

June 1935, 2 brothers lifted off from Meridian, Miss in the latest version of a 1929 Curtiss Robin on what would become a record breaking endurance flight. Powered by a 165 hp Wright radial, the 3 pas (pilot up front, & 2 SBS passengers behind), the otherwise unmodified Robin had an engine servicing catwalk & sliding top hatch for transfer of fuel & supplies from a plane above them. They received supplies 432 times by air to air transfer. They landed July 1 after 27 days continuously in the air. Their world record was 653 hours, 27 min. A Curtiss Robin was later used by "Wrong Way Corrigan" to cross the Atlantic in 1938. In 1935, man had only been flying for 32 years. Great advances had been made, but aviation was still not far from its infancy.

B.m.b Engine Endurance Flight in 1938

May 1938: A unique Lenape Papoose 50 hp 3 cylinder. radial powered Piper Cub flew nonstop from Newark, NJ to Miami, Fla, using "car to plane" transfer along the route, using a rope & 5 gal cans. 63.5 hours & 2,390 miles. The engine literally shook things to the limit of human tolerance. The later 4 cylinder horizontal opposed engines were much smoother, but rough compared with the 6 cylinder versions. Lycoming tends to use 4 cylinders well beyond Continental, so Continental is much preferred for engines between 145 & 200 hp.

B.m.c Engine Endurance Flight in 1958

Dec. 4, 1958: A Cessna 172 took off for a nonstop endurance flight. On Feb. 7, 1959, 64 days, 22 hours, 19 minutes and 5 seconds later, it landed in the Guinness Book of World Records. The nonstop flight record remains unbroken. That's 1558 hours & 19 minutes on an engine that at that time was rated for 1,200 hours between major overhauls; often with top overhaul midway. Except for the pilot's seat, everything was removed from the interior. They carried 47 gal. of fuel in the 2 wing tanks, & a 95-gallon fuel tank inside next to a mattress and internal access to both fuel and oil lines. Once each day, the Cessna was flown 20 feet above a desert road. A line dropped to the fuel truck raised a hose up to the aircraft so that 95 gallons of fuel could be pumped into the belly tank. The process took three minutes.

B.m.d Engine Endurance Flight in 1986

December, 1986: Amazing Record Breaking Round the World Flight.

Outstanding aircraft designer Burt Rutan designed a truly exceptional plane specifically for the round the world record. It has long been known that it is very difficult for a max gross to equal or exceed twice its empty weight. The Voyager T.O. weight was 4.3 x empty weight; 10 x structure weight.
Specs & performance: Length: 29'; Span: 111'; Empty - Gross weights: 2250 lb. - 9694.5 lb; L/D (lift / drag ratio) similar to that of high performance competition sailplane; 122 max speed.

Statistics of Rutan Round the World Record Flight: 26,366 statute miles flown; nearly 3 hours to climb to 8,000' initially with 110 + 130 hp Continental engines at max power; 11,000 ft. average altitude; 1,167 gallons of Av-gas in 17 tanks on TO, 18 upon landing; forced to circumnavigate around 600 mile wide storm; 100 people supported flight for the time in the air. Cost: $2,000,000 of solely private funds and donations; & 18 months to design & build the Voyager; averaged 116 mph; in 9 days, 3 minutes, and 44 seconds; just over 216 hours. Nearly twice the previous record of 12,532 miles by a B-52; composite material (graphite, Kevlar, and fiberglass); First test flight on June 22, 1984, the Rattan brothers, Yeager, and hundreds of volunteers had spent more than 18 months and 22,000 hours working on the aircraft; more than a year-and-a-half of testing and modifications on Voyager; at 8:01 a.m. on December 14, 1986 the Voyager TO after a 14,200 feet roll on a 15,000' runway. The author & his wife were among nearly a million people who saw the Voyager at AirVenture Oshkosh soon after the record breaking fight. Not among the many who saw it land, unfortunately.

B.n. Experimental (homebuilt or military) vs. Factory Built Lightplanes:

For several decades the homebuilders have built more planes than the major Genav (general aviation) manufacturers have produced. They are thus found in abundance on the used plane market, too. Homebuilts can be as safe as factory built planes, but statistics should be considered: Lightplanes are less likely to have structural failures, or other potentially disastrous problems as large jet airliners, but they are not immune to them. Basic design philosophy & expertise are major factors in the safety of any plane. Flight time & the number of take-offs & landings are factors in determining most problems. That number is obviously related to the number of that design flying.

Some design problems on large & small planes alike, unfortunately, are discovered by flying them; generally without injury. Observant pilots & mechanics find indicators of cracks, etc., before they become serious, & pass the word through the FAA & manufacturer to alert other users. Pilots sometimes discover flutter, controllability, or other aerodynamic problems. Unfortunately if found after it has caused an irrecoverable flight condition, or a major structural failure has occurred, they could be discovered at the expense of all aboard. Numbers can protect the pilot & passengers. If there are hundreds or thousands of a specific model built, someone else will most likely find the problem before it puts you at risk. If only 3 or 4 have been built, & they are flown only an hour per week, there just might be an unpleasant surprise for the builder who flies 300 hours per year. Amateur aircraft designers may study to learn a great deal, but it is unlikely that they can match that of a PE who is also a full time engineer for one of the major aircraft designers. The author certainly does not consider himself qualified to design a plane. There are some very serious subtleties such as flutter that are not easily understood by amateurs. He has seen the work of far too many "counterfeit engineers" who came up through the ranks to think he could step so far form his own training as to design a plane.

The new Sportplanes (LSA) are not required to pass the lengthy certification process. Some are certainly professionally designed, but that is not mandatory. There is no requirement for any serious flight testing program. The mainstay lightplane manufacturers that have moved into the LSA market probably have treated the design as thoroughly as their certified line. The Cessna Skycatcher was as thoroughly designed & tested as their certified line, but is being built, at least in part, in China. Piper's sportplane is being built in the Czeck Republic. It is probably as well designed as the Cessna LSA, but the author would feel safer flying in a plane built by an amateur homebuilder who is very concerned for his own safety; IF it were as well designed. Considering the U.S. economy & projected over-taxation the Cessna & Piper action is a serious detriment to the U.S.; to sending work out of the country; similar to buying foreign cars. This discussion calls to mind the "Undisputable Facts": If the U.S. were to cease all forms of producing products that can be exported & consumed domestically, all such products would of necessity be imported. With nothing to export, the country would expend all available money & literally starve to death. The same thing would happen if Americans buy foreign cars & electronics, etc. It would just take longer.

Cessna claims that their LSA design philosophy includes assurance of adequate, or better yet, the very best performance features. Undoubtedly Piper's LSA design philosophy is the same. Stall speed & characteristics are very important. A few planes tend to drop 1 wing when they stall; a very few even enter a spin. Stability is an important advantage for XC planes, or those to be flown by moderately skilled pilots, but stability actually reduces aerobatic maneuverability, or dog fighting capability. Military trainers generally actually have dangerous stall characteristics because they sacrifice safety for some aspect of performance; & such sensitivity is considered better for training military pilots. Some lightplanes, & many homebuilts, trade a little safety for improved performance. Some airfoil designs (& there are many) sacrifice a broad CG range for cruise speed. Some planes stall without a warning; most do not. Some stall at what many would say is too high a speed, in the interest of increasing cruise speed. Some, like Beechcraft & Cessna, seem to place safety ahead of all else, but still offer excellent performance & utility.

The more maneuverable a plane is the more likely it is to be somewhat unstable. Release the stick & it may elect to start a maneuver on its own. The world famous Pitts biplane was the leading aerobatic plane for nearly 50 years. The author knew it should be touchy, so was shocked when it seemed to have stall characteristics as gentle as his Cessna; even stalls out of turns. It certainly was more maneuverable, though. And the landings also seemed just as easy, except that as it slowed on the runway, it seemed to have a mind of its own. He had to respond very quickly to keep it on the runway when it decided to veer off. He also found the Timm & T6 (both WWII trainers) to be less touchy than he expected. Flying the famed P-51 remains but a dream for him, but the story is that if a pilot applies power as quickly as he would for most planes, the P-51 (& Corsair, & similar WWII fighters) it will actually roll to the left & crash. Unfortunately, that was demonstrated in the early 2000s, when one of these 2,000 hp monsters rolled on T.O. & destroyed it & another treasured Warbird at AirVenture Oshkosh. Both pilots survived, fortunately. The joy & excitement of flying a P-51 can only be imagined by most pilots, including the author. In speaking with the 4 WWII P-51 pilots that the author has the privilege of knowing, the excitement remains. One who he speaks with frequently brightens up at the mention of the P-51; like his 500+ mph dive on 1 strafing run, & later, nearly shooting down a ME-262 jet (which some friends accomplished).

When the author & his pilot-wife decided that it was time to buy a larger plane, they wanted the safest thing in the air for their new 1 year old girl; & her 3 brothers; 2 to 9 years old. Accident records were a factor, but so were things like stability, ruggedness, stall speed, cruise to stall ratio, reliability, AD notes (many or few), & the number of the model flying. A large number flying would mean that there were many planes of that model that might encounter the same unusual or difficult conditions before it might involve those 4 precious kids. It may seem harsh, but better to let someone else learn the hard way. In the case of Experimentals there will be very few flying, so little historical information. At least ask for the number being built, flying, & the accident history. That may provide insight into the safety of any plane of interest. Obviously consider the more critical items listed above, like stall speed. Cruise speed is a nicety; stall speed is a safety issue. Stall characteristics are also very important. Many homebuilt designers overemphasize speed at the expense of safety. There were, in fact, 2 safety issues that were discovered long after the author & wife bought their Cessna; vapor lock & tail blanking. Neither caused an accident, but either might have. They contacted Cessna on the vapor lock, but it was several years before anyone actually determined the subtle conditions that caused it, & solution. As for AD notes, Cessna has only a fraction of the number of AD notes as most competitors. Such directives indicate unexpected design or material problems. Factory built planes were required to pass rigorous flight testing & design analyses before the certification procedures qualify the design for marketing. Homebuilts are not certified. Some are certainly professionally designed, but that is not required. In fact, many homebuilt designers have absolutely no formal training or knowledge of either structures or aerodynamics. There is no requirement for any serious flight testing program.
In researching thru some antique aviation books & journals the author once found that the “Grand Old Lady” (also the title of one fascinating book); the DC-3 (C-47 military designation). The DC-3 was flown by several airlines from the 1930’s to the ‘50s, & a few are still in regular use virtually all over the world. One airline advised its pilots to reduce power, & thus speed, significantly in heavy turbulence. Turbulence, of course, means going from normal 1-g to typically <2-g, & occasionally to - 0.50-g or so. The airlines that did not slow down required 50% higher maintenance to engines & airframe, including major sections of ”skin” replaced even though most turbulence constituted a minor portion of the flying hours. The book listed the number of various items such as engines & tires, that it had replaced over its lifetime. Those studying the history estimated that 1 particularly high time DC-3 had taxied 100,000 miles. Although it topped out well over 200 mph, it was normally cruised at 150 mph. It was far superior to any other plane of its purpose & time; regardless

of country of origin. It was usually powered by the superb Pratt & Whitney or Wright radial engines between 1,000 & 1,200 hp. Some were powered by Canadian engines. A few post WWII were powered by Mitsubishi engines, with poor operational reliability. Over 16,000 were built & 400 were in service worldwide in the year 2000.

APPENDIX C: User -Friendliness, Practicality, Complexity, & Cost; Aero Navigation & Planes

C.a User Friendly

The simplicity, accuracy, technology, cost, & training required vary appreciably between the different Aero Navigation systems. Most are relatively easy to use, though some require a moderate level of technical expertise &/or training. The above Aero Nav systems, & those to follow, indicate the simple & the complex. No engineer will have difficulty understanding any Aero Navigation system; nor will he have trouble using them, as long as he obtains the necessary rating & proficiency. Most will not (some may) have the means to obtain the necessary training & experience to be approved for the revolutionary new concept that is described in detail in Aero Nav system no. 33; Revolutionary New Concept B. Very few will be able to comply with Revolutionary New Concepts A & C. Most engineers will be fascinated by these 3 extraordinary new concepts; but also with most other Aero Navigation systems described in later systems. Engineers will find that obtaining licenses & ratings from the private pilot's license to the instrument rating shockingly easy. It will prove to be easy & pleasant to fly VFR & IFR by use of any available Aero Navigation system, including any type of instrument approaches that he learns to use. Most Aero Navigation systems are not only user friendly, but surprisingly capable of providing enormous amounts of Aero Navigation information.

This course is intended to provide insight into many interesting technical details on the avionics & skills required, & the process of navigating using each System. The FAA declares only 16 airports to be congested. Whitman field at Oshkosh Wisconsin is not among them, but for 9 days of each year it actually handles 10 times as many movements as the busiest airport in the US (& thus the world).

C.b Practicality:

Gen-Av pilots, like all other, use Aero Navigation to locate any of the 16,000 airports that are available to them, vs. only 600 that are used by airlines. All 600 airports serving airlines have instrument approaches, so are easily accessed by VFR flights even with minimal avionics. There are no Navigation Aids located at most of the remaining 16,000 airports, so IFR approaches sometimes require additional Aero Navigation techniques or avionics. Many of the remaining 16,000 airports have instrument approaches, but many do not. Lacking an ADF, LORAN or GPS some fields would require the use of map reading to locate. As indicated in the No. 3 Aero Nav system (Map Reading) that is easy & precise day or night. Most airports in the U.S. are within range of a VOR, although many cannot be received until airborne. Finding even isolated airports is generally easy, as shown in several of the Aero Navigation systems described in this Aero Navigation series. There is an airport within a few miles of virtually every home, business, manufacturing plant & vacation attraction in the country.

A typical lightplane flight shaves 10% off of freeway travel distance, without any stop lights, toll roads, or traffic tickets. Much more than 10% is common. Freeway driving time is typically 2 to 10 times that of flying a lightplane. In the Northeast US, driving usually takes orders of magnitude longer than a lightplane because of the generally snail's pace on other than freeways. The author's most often taken flight is 900 miles from Houston to Gallup, New Mexico, vs. 1,200 freeway miles. Even with much of the freeway having an 85 mph speed limit, a moderate speed & power Cessna was several times as fast. T.O. soon after sunrise allowed arrival in GUP in time to drive to Zuni to purchase jewelry and other items for his wife's Indian Jewelry shop. Driving meant a night in a motel & late arrival on the second day. In winter, with the possibility of icy roads, the Cessna advantage grew.

The convenience & practicality of Genav, regardless of flight experience & the extent of the avionics package & Aero Navigation systems, is overpowering. A long drive to the airline terminal, & a rent car trip of several hundred miles is not uncommon for airline travelers; 1 or 2 hours the norm. Genav planes can often land within a few minutes of the destination. Many pilots actually taxi up to the business or tourist attraction that they plan to visit. The necessity of driving as much as one hour from any point in the U.S. to the nearest airport is, indeed, uncommon. Since 9-11 the total time for even very long trips in slow lightplanes generally beats airlines because of the early arrival requirements, & longer trip to the airline terminal than to small airports. When his kids were young the author frequently took his family to Disney Land & landed nearly within walking distance. The same was true of many other tourist attractions, including the New Jersey beach; to a dive spot in the Florida Keys (once SCUBA dove only a few feet from the plane); Matagorda Island in Texas; Cape Hatteras; Martha's Vineyard; Cape Cod; To visit family in central MO they could have walked home from the airport; vs. a 2 hour drive from the nearest airline terminal. One of these trips resulted in a self grounding that is mentioned elsewhere. On a camp-out on a beach in Northern Maine he was bitten on an eyelid by a large green fly. The vacation included following the Atlantic coastline to the Florida Keys, with numerous stops at attractions along the route. Soon after leaving NY City he could not fly safely. Fortunately his wife was qualified to fly so continues the flight to Florida & along the Gulf Coast. There is no better way to see coastlines, including numerous sunken ships, than a lightplane. The same is true of the Grand Canyon, mountains, & numerous other attractions.

On one business trip from Alamogordo to a major scientific company near Boston, the author's co-workers found the hard way that they should have accepted his offer to fly there in his then new Cessna. The long tiring & treacherous (New England road conditions) rent car drive required nearly as long a time as total flight time by airlines.

Carrying high value, fragile, or large, heavy "objects", is difficult or impossible for airline travelers; easy for Genav. The author confirms this when he occasionally accompanies his wife on a buying trips by airlines; returning with a moderate amount of Indian jewelry; vs. a vastly greater volume & weight allowance in the family Cessna; & without the risk of damage or theft. They have even carried life sized bronze sculptures weighing 2 or 300 lb. (well secured, of course) in the family Cessna; impossible by airlines, & difficult in a Suburban. Salesmen who need large or heavy sample cases or demonstration models simply cannot travel by airlines; nor are private automobiles generally practical. The author developed an elaborate 60 lb. sales demonstration case that permitted salesmen to demonstrate a patented electronic relief valve system to potential power (& other) plant customers. He designed a working scale model of the valve with diffuser pipe, & wired in a programmable micro processor to trip the valve when pressurized by a nitrogen bottle. It was extremely difficult to transport by airlines, & locate nitrogen bottles at the destination. Cars work, but are very slow. A lightplane is the most practical way to transport these demo cases. They were shipped all over the world, but within any country a lightplane is the best.

Literally thousands of "traveling salesmen" have increased their productivity, sales, & contact frequency by large factors by learning to fly & buying an all-weather lightplane, & avoiding long drives & airlines. The difference in the number of contacts in a week is enormous. The size & weight of many sales kits or samples prohibits airline travel. The often very long drives from airline terminal to customer plant are eliminated. One week long trips are often reduced to 1 day trips; back with the family every evening. A typical trip might be as follows, by the 3 modes available. Just for kicks, a quick look at busses & trains, too.

Assume, since it is a frequent trip for the author, La Porte, TX to Gallup, New Mexico. A company can justify a fast plane for their salesman; so consider a Beech Bonanza, or Cessna 210, both fast, safe, well proven, reliable planes. Or an equivalent Piper though most pilots would prefer the former two.

A comparison between the options for traveling between the Houston area & West Central New Mexico is summarized:

T41 (La Porte) TX to Gallup New Mexico via high performance planes such as the Cessna 210 or Bonanza:	4-1/2 hours.
T41to Gallup via airlines: Time, including driving & mandatory early arrival at terminal:	9 hours
T41to Gallup via personal vehicle; including one motel stop:	18 hours on road; 32 hours total
T41to Gallup approximately 24 hours by train, which includes either the route via Los Angeles; or the Chicago route; 2 bus trips & 2 train trips; by the second of only 2 available train routes:	26 hours
Bus: Approximately half of train cost, but much more expensive than airlines; approximately:	24 hours

C.c Complexity:

The reader might ask, "How complex is it to fly & navigate a lightplane?" Actually, it is surprisingly easy to obtain a private license, & to navigate & fly an airplane. Few people actually just navigate; Aero Navigation generally involves flying the plane, too; quite a thrill & a challenge.

Any engineer will find all types of Aero Navigation relatively simple. Most drivers who have never flown in a lightplane might initially be overwhelmed by the complexity of the avionics & the thought of working on his private pilot's license. Even a brief introduction will usually eliminate his concerns. A private pilot's license affords adequate flying privileges & skills for most purposes. The instrument rating is the same way. The author had heard so many horror stories about the complexity & difficulty of the IFR rating that he was convinced he could not master flying IFR. From the first lesson to the instrument rating check-ride, he was convinced that he could not succeed on that particular flight. In each case he was relieved & genuinely surprised at just how easy really it was. Certainly it demanded a more precise heading & altitude hold than he had grown to accept, but he also found that it was actually easier to hold both precisely than to accept a small error, which inevitably resulted in a larger error.

Actual IFR flying proved to be a joy rather than the fearful experience that some claimed, & he expected. Such a joy that he has always filed IFR flight plans for “mid cloud height” at every opportunity; & watched for local IFR conditions so he could shoot local practice approaches repeatedly in near minimum conditions. For quite a long period the FAA Approach Control would allow him to fly an ILS, then a missed approach to enter the back course (opposite way) down the same normally busy runway, & repeat. He often shot 8 or 10 practice approaches before returning to his home airport. Eventually as traffic built he had to give up that enjoyable, proficiency building, challenging entertainment.

A private pilot’s license can be earned in only 35 to 40 flying hours, plus a few hours of ground school. A sport pilot license can be obtained in 2/3 of that. Both flight & ground training include sufficient knowledge & hands-on application of aerial navigation to permit a student pilot to navigate a plane under all normal VFR conditions. It will include dealing with ATC (Air Traffic Control) both enroute & during the take-off, departure, approach, & landing phases of a VFR flight. It will even include Aero Navigation for a night check-out; except for the sport pilot. His training in the primary aerial navigation systems will be sufficient for understanding enough theory & practice to prepare him for all basic, frequently used Aerial Navigation. systems. It may not include GPS, but nearly everyone will buy & use a hand held GPS, but probably not an IFR certified panel mounted GPS. New Aero Navigation systems can be easily learned & practiced. He will also be prepared to properly respond to any emergency situation that he is likely to encounter as a private pilot. Aside from the essential flying portion of the training, he may learn most of what he needs to know from a Private Pilot’s Handbook (such as the 1 referenced in Appendix K) through home study, although some student pilots do attend a formal class. He must pass a “written” (on computer, actually) exam after his CFI (flight instructor) discusses the pertinent subjects & “signs him off” (recommending him as qualified to be a private pilot) for his official private pilot’s check ride. Most student pilots fly only once or twice per week, so spend about 6 months earning a private pilot’s license. Any CFI can do what some flight schools encourage; an expedited course where it is possible to earn a private pilot’s license in 2 or 3 weeks. Both written & flight exams are required for a private pilot’s license, which allows a pilot to safely carry passengers under VFR conditions anyplace in the U.S. In fact, most countries honor the U.S. flying licenses. Some “backward” countries do have more restrictive & questionable policies. For example, Mexico refuses to allow either VFR night flying, or IFR, in single engine planes. Most, if not all Socialistic (& all Communist) countries prohibit or seriously restrict the “precious freedom of flight”, as well as personal freedom in general. Socialism, like Communism, is indeed excessively restrictive to all personal freedom, so Gen-Av certainly suffers under Socialism. Communist Russia, China, Cuba, N. Korea, etc were/are uncomfortably similar to Hitler’s “**Socialist Democratic**” Germany. The socialist countries in Europe are also extremely restrictive to flying & personal freedom in general.

C.d How Easy is it to Actually Start Flying?

There are always many FBOs, CFIs, & a wide variety of pilots who are willing to assist you in making a rational decision on how to reach your specific flying goals. Many CFIs are anxious to help so they can build time & improve their own knowledge & skills.

With 16,000 Gen-Av airports across the U.S., a trip to the nearest airport should be easy. A little “hangar flying” (common expression for “talking flying” with fellow flying enthusiasts) will provide valuable information based on experience of a diverse group of pilots who fly planes for a wide variety of reasons. Some such advice may not be the best; or may conflict with others. It seems that every design, regardless of how poor it performs or even how dangerous it may be, has some fans who brag it up at every opportunity. At the least take positive claims with a grain of salt, & give negative comments more credibility, if the issue is safety. If in doubt, call the AOPA for clarification.

Most of the above airports offer flight training by at least one method. Most have at least 1 FBO for fuel, aircraft maintenance & usually flight training. A large portion have flying clubs & partnerships. The cost of all services & training varies widely across the nation, & even within one metropolitan area.

The cost of a pilot’s license varies, but a private pilot, or possibly a sportplane license, should definitely be considered a minimum before continuing, even if the long term goal is only to fly an ultralight. Most utralights are still functionally an airplane (except for a few that are closer to a hang glider or parachute). Ultralights are not legally an airplane, nor can flight time in an ultralight be “logged” as flight time in an official pilots log book. None are monitored by the FAA, so almost certainly do not meet the FAA aerodynamic stability or structural requirements that all certified aircraft must meet. An utralight is also very limited in capability & performance, but it still requires skill & knowledge that can only be safely acquired from training under a CFI. Specific limits for an ultralight are listed below.

C.e The Requirements for Obtaining a Pilot's License:

Realistically an Aero Navigator needs access to a plane; the first step may be to start flying lessons.
The reader might ask, "How expensive is it to learn to navigate a lightplane"? It would be possible to learn Aero Navigation from appropriate avionics manuals & the Private Pilots Handbook such as that referenced in Appendix K. It might be possible to expand knowledge by practicing Aero Navigation while riding with a pilot-friend. Of course, it would be more practical to learn to fly a plane, which also entails learning & practicing Aero Navigation. Actually, the cost of practicing Aero Navigation, & flying, is well within the reach of most Americans, depending on where they place it on their priority list. The author once knew a pilot who said he couldn't afford a plane, although he earned literally 10 times that of a subordinate who had just purchased a new 4 place plane. It's all about priorities.

The Private license is the most useful basic license. Commercial, CFI, Instrument, & ATP build on the Private license. The Recreational & Sportplane licenses are both somewhat limited.

The more carefully a flying enthusiast researches all options the more likely he is to make the best decision. It is best not to select either a license or a type of plane on the basis of one friend's preferences, high speed cruise, or looks; but rather on practicality, utility, overall specs & especially safety.

Even a student pilot must be able to navigate; thus Aero Navigation is essential for all flying as PIC (Pilot in Command). Recreational & sportplane pilots (similar licenses), as well as the more advanced licenses & ratings, all require Aero Navigation. A sailplane & hot air balloon pilot also needs Aero Navigation capability so he can monitor progress along a route, establish his position, & advise a ground crew of his location, so they can pick him up. Communication equipment is also obviously necessary for contacting the ground crew. Of course, the sailplane pilot hopes to avoid off field landings, although virtually all free balloon landings are off - site.

There is no aerobatic rating or license, but training is essential for safe & enjoyable aerobatic flying.

There are no ratings or licenses for ultralight, but they must be flown under FAA rules & limitations; generally informally self regulated by national "Clubs".

C.e.a. Student Pilots License:

The only cost of starting to fly is for the time in the plane with a CFI. The mandatory flight physical is required before solo; usually after about 8 hours of dual instruction. Buying & studying a Private Pilot's Handbook before flying is recommended because it improves comprehension & facilitates the hands-on learning process. Total unambiguous verbal & written fluency & full comprehension of English (a definite hazard to all aircraft if less) are required. A student pilot's certificate expires in 2 years, regardless of the intent.

There are typically approximately 85,000 (a rapidly changing number) Student Pilots. A Student Pilot must be at least 16 years old to solo powered planes; 14 for gliders or balloons.

Before soloing a student pilot must pass an FAA physical; 3^{rd} class or better. Requirements: Student pilots need a current FAA "Medical" (Class 3 or better), & specified levels of related knowledge before solo. Class 3 medical requires freedom from medical conditions that might cause unexpected loss of motor skills, or consciousness. A Class 3 physical requires eyesight no worse than 20/40 in each eye corrected or uncorrected. Note that a waiver can sometimes be issued if beyond these values, depending on how bad the eyes are. A waiver for one eye (blind in other) takes 9 months. Wiley Post was blind in one eye. The author has known 1 eyed commercial pilots.

A student pilot must be at least 16 years old to solo powered planes, or 14 for gliders or balloons.

Limitations: A Student pilot may fly solo only within specific limits set by his CFI; & under the FAA rules for a student pilot. Each individual flight should be approved by his Instructor.

C.e.b Private Pilot's License:

The first full-fledged pilot's license is the Private. Total unambiguous verbal & written fluency & full comprehension of English (a definite hazard to all aircraft if less). Difficult to understand accents, or poor comprehension of the language can cause serious risks to all involved.

A private pilot is, except for Special VFR, limited to operation with 3 mile visibility & 1,000' ceiling in controlled airspace, unless he obtains an instrument rating.

A private pilot must be at least 17 years old; 16 for gliders or balloons. He must demonstrate all of the above skills & ability to a flight examiner, & pass both oral & written exams covering all aspects of flying & the use of the airspace.
A private pilot is allowed to carry passengers in any plane that he is qualified to fly.

He must have received training in a wide variety of activities, including take-offs, landings, "ground reference maneuvers", Aero Navigation, cross country (dual plus 5 hours solo), 3 hours of dual night, & 3 hours without ground reference (IFR).

The national average cost for obtaining a private pilot's license in planes in 2009 was $7,000. That cost assumes training at a certified flight school, including "1 on 1" ground training, as long as the student also studies the Private Pilot's Handbook at home. The cost of any type of pilot's license certainly can be reduced by shopping around. $2,500 to $5,000 may be possible for the frugal pilot. The CFI must still be certified, & the license earned will be valid. Many independent CFIs give lessons to help "support" a plane, or to build flying experience & time. A CFI must meet a few requirements to maintain his CFI. One of those requirements is "signing off" (recommending a student pilot for a flight test) a few pilots for a license. If the CFI is having difficulty finding enough students he may reduce his fees.

Another factor is that non commercial flying is permitted to use automotive fuel, which affords a cost savings. Auto gas is actually safer than Av-Gas for many aircraft engines that are susceptible to plug fouling from the higher lead content of Av-Gas. After the year 2000 fuel price inflation, the difference between automobile fuel & Av-Gas cost for planes soared from roughly $0.50 more than auto gas to between $1.00 & $2.00 more. Use of auto gas literally saves $4 to $30 per hour depending on the engine size. A plane owned by the student is allowed to use auto gas.

There are approximately 235,000 private pilots in the U.S. To obtain a private pilot's license (under FAA Part 61) a person must first obtain a student pilot certificate, accumulate a min. of 40 (35 under FAA Part 141) flying hours, of which at least 20 hours must be dual instruction. The 3rd class medical that he needed for the student pilot's certificate lasts for 5 years if under age 40, & 2 years if 40 or over. This includes eyesight no worse than 20/20 in each eye corrected or uncorrected. Note that a waiver can sometimes be issued if beyond these values, depending on how bad the eyes are. If a pilot (private or commercial) loses an eye, he can obtain a waiver for one eye. It takes approximately 9 months, including demonstration of flying skills. To fly small planes of a different "type" simply requires a "check-out" by a CFI (Certified Flight Instructor), or in some cases any pilot who is qualified to fly that plane and personally trains the pilot on aircraft systems & operations, including demonstration of flying skills in that plane. An example would be a pilot who has only flown the 2 place (2 passenger; including pilot) high wing, single engine, 100 hp, fixed gear Cessna 150, who wishes to fly a 6 place, low wing, single engine 300 hp RG (Retractable landing gear) Piper. Only a "check-out" is required, but with the addition of a larger engine, RG & CS prop, it would be a lengthy check out. To transition into a light twin, a multi engine rating is required. In larger or more complex planes, however, a "Type Rating" is required. "Planes heavier than 18,000 lb., & turbojet or turboprop powered planes, among others, require a separate "Type Rating" for that specific plane.

Although a Private Pilot cannot fly for hire, he can "share expenses", such as airplane rental fee or fuel cost. A private pilot can also fly for his employer as long as his salary is primarily for other activities, such as engineering.

C.e.c Recreational Pilot's Certificate

The recreational pilot license, introduced in 1989, is similar to the more recently developed, & very popular sport plane pilot's license. There are only approximately 250 licensed recreational pilots. It requires about 3 / 4 of the training, so cost is about that portion of that of a private pilot's license; a major merit for someone who is not certain they want to continue flying. It is primarily for someone who wants to, as the name implies, fly for recreation only. A recreational pilot certificate is limited to daytime VFR, but its more serious limitation is the prohibition of travel beyond 50 miles from the departure airport. It is also limited to non-tower airports. Limited or full upgrade to Private Pilot is possible, so it is a good starting point. This license does not limit to lesser planes, so a Recreational Pilot may fly higher power, larger, or 4 passenger planes. He may fly high aerobatic planes, although special aerobatic training is essential for safe aerobatics.

C.e.d Sport Pilot License

The sportplane pilot license was approved in 2004. It required total unambiguous verbal & written fluency & full comprehension of English (a definite hazard to all aircraft if less).

If a two passenger plane is adequate for a pilot's needs, the most serious disadvantage of the sportplane license is the restriction against IFR.

It requires only 50% of the training required for the private; thus cuts cost in half; not over $3500 for the 2009 U.S. average. It authorizes piloting only LSA (light sport aircraft; an entirely new category of planes), but the LSA suits the needs of many pilots very well. Further, quite a few older 2 place planes qualify as LSA, as do many homebuilts. More on homebuilts later, including cautions. The LSA certification & sport pilot license are limited by certain activity, weight and speed restrictions. Planes are built according to "industry consensus standards", so there is a possibility that some planes will not perform as well, or be as safe as desired. Some certainly are professionally designed, manufactured, & tested, even though they are not actually certified. The sport pilot certificate, unlike the recreational pilot certificate, is amazingly popular. It is a very practical license for those who want to cut costs, or who can no longer pass the flight physical, or who no longer need to carry more than 1 passenger. The LSA & new rules have resulted in a rush to design & produce LSAs.

Not all flight schools offer Sport pilot certificates. Training time, & both the flight & written exam requirements for a Sportplane pilot certificate are less stringent, which reduces the cost of training. Most Sportplanes have considerably less powerful engines than the typical lightplane, reducing the cost of fuel, & presumably engine wear allowance.

Limitations of Sport Plane Pilot's license: flight not over 10,000', except higher in mountainous terrain; then up to 2,000' above ground level, Day VFR; no night or IFR flying. 2 pas. max. Max level flight speed is 138 mph; possibly realistically 125 cruise. Nearly as fast as the older "bullet proof" (zip for maintenance) smooth running 6 cylinder Continental powered Cessna 172, 4 passenger lightplane. This 145 hp plane tops out at 139 mph, & cruises between 125 & 130 at altitudes between 2,500 & 12,500' & 75% power, until the engine power drops to 63% at 12,000'. It cruises between 119 & 126 mph between 2,500 & 12,500' at 65% power. It has a 1,045 lb. payload, cruises nicely at 15,000', & easily handles most of the mountain runways in the U.S. Several older planes that qualify as a Sportplane include the mid 1940 era Taylorcraft BC-12D steel tube, wood & fabric 2 place 65 hp taildragger that flies like a jewel & cruises 95 mph on <3 gallons of gas per hour. A friend of the author was the son of a pilot who was instrumental in Charles Lindberg's involvement in flying. This young man flew from Alamogordo, New Mexico to the far NW corner of the U.S. (& back) on his honeymoon in his beautiful little T-Craft BC-12D. At 95 mph it still travels much faster across the country than any car. There are literally dozens of older planes that qualify as Sportplanes, but the author considers the efficient little T-Craft one of the best performing & flying.

A sport plane pilot may not fly in any airspace that requires radio communication without a checkout on same. That includes Classes A, B, C, & D. But sport plane operation is never authorized in Class A airspace. The sport plane pilot is not as limited as the recreational pilot, but the license costs roughly half as much as the private pilot license, so it is more cost effective & practical. The only disadvantage of the sport pilot license vs. recreational pilot is the type of planes; smaller & lower power.

The sport plane pilot's license was established by the FAA in the year 2004, after extensive negotiation, having been proposed by the EAA (the Experimental Aircraft Assn was established in 1957, & expanded over the years in influence), which started the "ball rolling", & worked with the FAA for several years, & the "also very important" AOPA (Aircraft Owners & Pilot's Assn; has 415,000 members). To obtain a sport plane pilot's license a student pilot must first obtain a student pilot certificate and accumulate a min. of 20 flying hours, of which at least 15 hours must be dual instruction.

He must have received training in a wide variety of activities, including take-offs, landings, "ground reference maneuvers", 2 hours of dual & 5 hours solo cross country using Aero Navigation methods. He must demonstrate all of the above skill & ability to a flight examiner, & pass both oral & written exams covering all aspects of flying, including the use of the airspace. There were 3 primary reasons for the sport pilot license:

1. Simplifying & reducing the cost of flying for the beginner, without severely limiting the utility of the airplane.
2. Allowing older pilots to "drop back" somewhat as they age, or as their need is reduced. Private pilots who intend to opt for sport plane category have already received & demonstrated flying abilities & knowledge, so are not required to take any training, except for the routine BFR (Biannual Flight Review). They may fly only on the basis of having passed the medical requirements of their state driver's license "IF" they did not fail their most recent flight physical.
3. To reduce cost, & sometimes severe regulatory impact of minor medical problems, the impact of which the FAA policy "blows out of proportion". Medical problems can, per current regulations, as applied to the more stringent FAA licenses, often result in the need to spend tens of thousands of dollars for difficult, extreme, "usually unnecessary" tests. The FAA

recognizes the fact that many of these medical deficiencies could be proven to have no impact on a pilot's ability to perform functions by any medical doctor using elementary diagnostic tests, or a simple examination. The pilot could then fly perfectly safely without the outrageously expensive series of tests. That seems to have influenced the FAA as indicated by the sport plane designation.

Any pilot is obligated to avoid flying during any impacted period. Such conditions include those from ingesting certain medicines; & for that matter, drinking alcohol. Even pilots with valid flight physicals are required by law to ground themselves when under the influence of such substances. Sport plane pilots must be able to clearly speak, "comprehend", read & write the English language. Difficult to understand accents, or poor comprehension of the language can cause serious risks to all involved. For powered planes a sport plane pilot must be at least 17 years old to solo; 16 for gliders or balloons. There are approximately 900 licensed sport plane pilots.

C.e.e Advanced Licenses & Ratings:

Advanced licenses require a minimum total flying time as well as specified minimum additional training. All also require a BFR to verify adequate skill & knowledge. There is no reason to fear the BFR.

C.e.e.a Instrument Rating:

Minimum prior experience: Private pilot license, 50 hours min XC as PIC after receiving private license, pass instrument written (computer) test. 40 hours actual or hood instrument time, of which up to 20 could be in an official simulator; time sitting at home on any simulator without a monitoring CFI may not be included in the experience claimed. Min. of 15 hours in plane with CFII. Some hood with another pilot acting as safety pilot is allowed to reduce cost of CFII. Total unambiguous verbal & written fluency & full comprehension of English (a definite hazard to all aircraft if less). Flight training & demonstration of knowledge & skills.

One aviation training center advertises an instrument rating in 1-2 months with 12 week intensive ground school, & states a national average cost of $1,000 to $1,500; presumably in student's plane. Another advertises an instrument rating in 10 or 15 days for $6,000; $3,000 in student's plane. About $350 for the FAA examiner for check ride.

Extensive additional instrument training is required to obtain an instrument rating to permit flying legally and safely in clouds, or below VFR visibility minimums. IFR flying is considerably more complex than VFR flying because both enroute & the approach & departure procedures are much more restrictive & detailed. The Aero Navigation Systems used are the same as for VFR flying, except that more is demanded of an IFR pilot. IFR requires greater confidence in, & more detailed understanding of avionics (including instruments) than does VFR flying. As is typical of advanced ratings, a written exam (usually in recent years, on a computer), & an oral & flight check by an FAA examiner. The instrument rating was once touted as practical only for full time airline pilots; not for most commercial pilots & certainly not for private pilots. It has long since been simplified, & training shortened somewhat, & is quite practical for most "serious" pilots. The greatest concern for IFR pilots is that of maintaining proficiency. There are now approximately 300,000 instrument rated pilots in the U.S.

C.e.e.b CFI (Certified Fight Instructor):

Requirements include: Min. age of 18, commercial license, instrument rating. Total unambiguous verbal & written fluency & full comprehension of English (a definite hazard to all aircraft if less). Flight training followed by demonstration of knowledge & skill, including the ability to teach flying on the ground & in the air. Pass a check ride.

Maintenance of CFI & CFII requires a specified instructing activity.

C.e.e.c CFII (Certified Fight Instructor; Instrument):

Requirements include: Min. age of 18, commercial license, instrument rating. Total unambiguous verbal & written fluency & full comprehension of English (a definite hazard to all aircraft if less). Flight training followed by demonstration of knowledge & skill, including the ability to teach instrument flying on the ground & in the air. Pass a check ride.

C.e.e.d Commercial:

To be able to charge for his flying, a pilot must obtain additional training that leads to a commercial "license". A private pilot's license is a prerequisite for a commercial license, along with demonstration of additional knowledge & skills, after flight training.

Some commercial operations require an instrument rating as well as a private pilot's license.
Total unambiguous verbal & written fluency & full comprehension of English (a definite hazard to all aircraft if less).

Before taking his check ride, a commercial pilot candidate must pass an FAA physical; a second class medical, which expires after 1 year. Mental disorders & substance dependence are generally disqualifiers. Many commercial pilots obtain their commercial pilot license primarily as a means of improving their skill & knowledge level, & never actually fly for hire, so may fly with only a 3rd class medical. Many young pilots do instruct to earn money while building enough time to qualify for more serious commercial flying. Most licenses & ratings require passing both written & flight tests.

Commercial pilots must be able to clearly speak, "comprehend", read & write the English language. Difficult to understand accents, or poor comprehension of the language can cause serious risks to all involved.

There are approximately 130,000 commercial pilots in the U.S. A commercial pilot must be at least 18 years old, hold a private pilot license, & have logged 250 flying hours (190 under FAA Part 141). He must receive additional flight training & be able to demonstrate a higher level of flying skill & knowledge. He must have a 2nd class or better medical certificate. This includes eyesight no worse than 20/20 in each eye corrected or uncorrected. Note that a waiver can sometimes be issued if beyond these values, depending on how bad the eyes are. A waiver for 1 eye (blind in 1 eye) takes 9 months.

C.e.e.e ATP: Airline Transport Pilot:

There are approximately 145,000 ATP (Airline Transport Pilot) pilots in the U.S. The ATP permits a pilot to fly airliners as PIC, but it is possible for any pilot, with sufficient qualifications, to obtain an ATP that is limited to light twins or even a single engine aircraft. An ATP rating is not required by the FAA to "fly an airliner", as long as the PIC is so rated. An ATP must have earned an instrument rating in the past, but that rating does not appear on his license, since it is understood that the ATP is qualified to fly in IFR conditions. Although flying an airliner in VFR conditions "should not" be logged as IFR, airlines always "file" IFR.

An ATP candidate must be at least 23 years old, have 1,500 hours, 500 hours XC, 250 hours as PIC, 100 hrs night, 75 hours IFR, total unambiguous verbal & written fluency & full comprehension of English (a definite hazard to all aircraft if less), good moral character, commercial license & Instrument rating, meet aeronautical experience requirements applicable to the aircraft for which the rating is being sought, pass the written test, pass the flight check, & hold a first class medical. A first class medical must be renewed annually if under age 40, every 6 months if 40 or over. The most demanding of all licenses or ratings, the ATP requires flight training, & demonstration of knowledge & skills with an FAA examiner.

As stated in paragraph 3.1.3.3 the availability of U.S. based airlines to find adequate numbers of ATPs now, & into the future was placed in jeopardy by irresponsible irrational bureaucratic politicians in 2009.

C.e.e.f Type Rating:

A Type Rating is required for each very large aircraft, based on aircraft gross weight. An Airbus type rating does not qualify an ATP to fly a similar sized Boeing. Note that a type rating is not required for lighter weight planes. A Beech Bonanza pilot can fly a Piper Mirage or Cessna 210 with a simple check-out; & obviously the reverse.
One aviation training center advertises a type rating in the Airbus 320 for $30,000. Note that an ATP can be issued for SE planes; even a basic trainer class lightplane. The ATP is then limited to SE. A type rating for a larger aircraft is then mandatory, if his ATP is to be used for larger planes. A type rating is required for planes weighing over 12,500 lb or any aircraft powered by turbojet engines

C.e.e.g Multi Engine Rating
Like other ratings & licenses, specialized flight training, accompanied by ground school, or the equivalent, is required; followed by a demonstration of knowledge & flight skill. Each new rating or license improves knowledge & flight skill.

C.e.e.h Seaplane Rating

As above; appropriate training. A real joy to land & TO from water.

C.e.e.i Helicopter Rating

As above; appropriate training. Never obtained stick time in a copter, but complex & versatile; very high maintenance.

C.e.e.j Glider Rating

As above; appropriate training. Great fun & challenge

C.e.e.k Lighter Than Air

Hot air balloon, low density gas filled & blimp or rigid airship. As above; appropriate training. Great fun & challenge

C.e.e.l Commercial Astronaut License was developed in 2008 for the 2 SpaceShipOne pilots. Since most of its flight is as a glider, a glider rating is also a prerequisite.

C.e.e.m There are a Few Other Licenses & Ratings for Aircraft Mechanic, Ground Instructor or flying a few Unique Aircraft

C.e.e.n Options for Obtaining a Pilot's License or Rating:

C.e.e.n.a FBO with formal Flight School

FBO with a flight school (higher overhead usually results in higher rental rates at an FBO). Even an FBO will have some scheduling limitations. An FBO one of the best ways to assure top quality planes & CFIs. This is not to insinuate that any other option is unsafe or unsatisfactory.

C.e.e.n.b Independent CFI

An independent CFI with his own certified plane, a share in a plane (partnership), or his own sportplane, if interested in that category instead of a private license. An independent CFI, with his own plane, may be considerably less costly, & still adequate. This person might in fact be a fellow engineer who is, if anything, a cut above the average CFI. If cost is an issue, consider sportplane to reduce expenses. It is possible to upgrade a sportplane pilot certificate later to a private license, if desired.

An independent CFI, like all CFIs may enjoy instructing, & the benefit of help in affording a nice plane. If so, he probably does not instruct several hours per day, every day, but he must still meet the same requirements as a full time CFI.
He not only took the same courses, but is required to maintain his CFI by regular student "sign-off" for private license or advanced ratings. A CFI must not have many student rejections by the FAA examiner. He must attend refresher courses & seminars on the CFI programs. It may be possible for a student to continue flying the same plane after receiving his license, if scheduling permits.

C.e.e.n.c Enroll in a Flight Training Program at a Local College.

A college based flight training program may be one of the best. A word of caution; many formal programs including some at FBOs prefer to train pilots for jobs as an airline pilot. Although top quality in all respects, it may be best to avoid such programs. Long low angle approaches are nearly always the norm for airliners; never for lightplanes. The local FAA agrees with the author that flying a SE lightplane like an airliner is a tremendous waste of time & fuel. His comments included the "lack of benefiting from the utility of the plane". We also agreed that it leads to pilots who are incapable of making a safe emergency landing; having dragged slow SE planes in with relatively high power settings for 5 mile long finals vs. the more practical 1/8 to 1/4 mile long power- off final. Experience at power off approaches is mandatory for anyone who would like to be able to land at the field of choice without power, if the need ever arises. A local Cessna 310 pilot who tired of such impractical training flights bogging down traffic at his municipal airport commented that he frequently "turned inside of" 2 or 3 such training planes that were on final approach in his high performance Cessna 310 light twin, & turned off the runway before they reached it. The term "turned inside of" means turning in front of a plane on final approach, which is normally forbidden, & simply unwise. In fact, the "rule" is that the plane on final has the right-of-way; never turn in front of them. A very good rule of courtesy & safety; except when rude inefficient training programs interfere, & make it impractical. At that airport it was the norm.

C.e.e.n.d Join or Form a Flying Club

A flying club has the potential of reducing the cost of flying; some do not. Less of an investment than sole ownership, but not all clubs are economical or practical for every pilot's needs. Larger flying clubs usually offer a wide variety of types to suit many different needs; some specialize in one type. Most smaller clubs own only 1 or 2 planes. Most flying clubs offer flight training. A "sometimes economical" approach is to find a reputable flying club that suits the aspiring pilot's goals & budget. "Sometimes economical" indicates that a club should be investigated. Some clubs simply are not actually cost effective. If your intent is to fly only locally, & cost distribution is not well adjusted, you may in fact be subsidizing those who want fast, long range IFR equipped planes; possibly multi engine. Conversely if it is the opposite, they may not have a plane that suits your needs. Buying into & selling out of a club may be difficult; or a losing proposition financially. The AOPA has excellent pamphlets on how to form & evaluate a club or partnership. The critical item is assignment of costs to assure a fair cost balance. The author once joined a flying club where nearly all members flew professionally, so their monthly dues subsidized his limited expenditure. He paid a fraction of the usual rate for rentals for a single place Mooney Mite, several 2 place tandem & SBS planes, & even a new 4 place Cessna 172. The only fair club arrangement involves buying a "fair share" of the "current value" of planes on hand, & pay a fair share of fixed & variable costs. The current value changes as the planes build time. Each hour the engine runs should increase the engine overhaul allowance, as well as other "time related" costs, so the hourly fee should pay into a club reserve an amount equal to the overall time related allowance. The hourly "rent" fee should match the member's share of direct operating cost; based on flying hours. If not, some members will subsidize others in the club, & some will get a "free ride" to some extent. Conversely the "fixed cost", such as insurance & hanger or tie down fees, should be paid by each member's share of the monthly costs as dues. Clubs often operate more than 1 type of plane; sometimes trainers plus aerobatic plus VFR cross country planes, plus IFR cross county planes. Occasional scheduling problems, again, but a great versatility of type plane for any given flight.

C.e.e.n.e Join or Form a Partnership

Easier to form than a club. Less of an investment than sole ownership, but not all partnerships are economical or practical for every pilot's needs. If all partners want joy riding or VFR training; fine. Or if all want XC planes; & all want the same sophistication; VFR or IFR, all is well. Per the above, the AOPA pamphlets & advice on economical arrangements can assure a fair financial balance. The same basic cautions apply.

What might the cost breakdown be: Assume a Cessna 150 trainer with enough avionics to allow IFR training & IFR cross country. It is quite a capable plane for XC. A ball park cost might be: Fixed: Annual; $200 per 13 months, Insurance for 3 high time pleasure pilots $500 per year, Altimeter-transponder check $100 per 2 years, Tie down $40 per month, for a total of $101 per month; $33.74 per person per month fixed costs. Assume $10,000 cost for engine overhaul when engine reaches 2,000 hours, & the pilots will burn 4 gph & pay $4.00 per gallon. Hourly fuel cost will be $16.00 & engine overhaul allowance will be $5.00 per hour. Total cost is $21.00 per hour. Total cost per year will be $21.00 x no. of hours flown plus $33.74 per month. If a pilot flies 25 hours per year his total cost will be $77.42 per month, or $37.22 per hour. If he flies 100 hours per year his cost will be $208.74 per month. Add to that the initial cost of a used Cessna 150; assume $30,000, for $10,000 per partner. The value of the plane varies with general appreciation (typically rather than depreciation), & engine hours. Per the above, the plane loses $16 per hour in value.

A partnership is generally insured as a sole ownership. If one pilot has fewer flying hours, his insurance premium if sole ownership might be twice that of a more experienced pilot. In that case he should pay 2/3 of the total premium. If the partnership reaches 3 to 5 members it is declared a club by the insurance company, & the insurance rate will be as much as 10 times higher.

A partnership usually operates only 1 plane. It is like a full ownership except that fixed costs are reduced by a factor of 2 or more. Less benefit for a third partner, of course. Scheduling is not often a problem. Scheduling priorities & rules should be part of the initial agreement.

C.e.e.n.f Sole Ownership

There are numerous advantages of clubs & partnerships, but since many engineers move frequently, a sole ownership may be the only practical option other than rentals. In the author's case, engineering led to 2 long cross country moves after the purchase of their last plane, so a partnership would have presented problems. He also liked to do a few legal modifications & add many unique special avionics devices, including instruments.

A certified plane has merits, including the relatively high cost of a plane rental, unless it is flown too little to keep the total effective hourly cost down. Total access; no competing for schedules, total control over avionics, paint job, upholstery, etc. Of course, such items cost more for aircraft than for cars since materials must be certified by the FAA. Conversely, since aircraft materials are all top quality, the upholstery should last for over 3,000 flying hours.

C.f How does one know what plane to buy?

Buy a Flying magazine; or subscribe to Trade-A-Plane; or pick up an old copy from the local airport.

The internet is limited only by the ability of the user to think of a variety of names & planes. Expensive color brochures have largely given way to elaborate on-line videos & spec sheets.

Go to a library & study books such as Jane's All the World's Aircraft, or Aircraft of the World by Doubleday (not jet fighters; but lightplanes). Conduct Internet searches for planes of interest.

Go to air shows, or even the EAA's AirVenture Oshkosh. Great for a day; difficult to see it all in 9 days. Calif. & Fla. have some excellent air shows, but there are many similar air shows all over the U.S. Even small air shows can overwhelm any pilot-want-to-be.

Remember that beauty is in the eye of the beholder, & that looks do not necessarily assure safety, utility, ease of flying, or even high cruise speed. Also that speed should not be the only criteria; some of the faster planes traded safety or even stability for speed.

Obtaining a private license in a glider is another option, but not a strong Aero Navigation variant. It's quite different since you must stay up to practice turns, stalls, etc. Learn to soar by riding thermals. In the U.S. the aerial tow dominates, although both winch & auto tows are available. Europeans generally use winches, where bungees are still used occasionally, with limited altitude gain. A private license in powered planes is not a prerequisite for soaring; nor does a glider license permit a pilot to fly powered aircraft. Each is, however, excellent preparation for the other.

C.f.a How does one know which plane is really appropriate for his needs?

Every flying enthusiast wants a 6 place 300 mph plane that burns only 2 gph. Those people also want a Corvette that carries 4 people at 220 mph & gets 50 mpg. But what is realistic?

Visit local airports, look around, & ask a lot of questions. Speak with as many pilots as possible. Take every answer with a grain of salt. Most pilots are willing to help sell you on Genav, & inform you. A word of caution; many favor just 1 "plane"; often to the exclusion of others, even overlooking serious weaknesses of their favorite. A plane that is excellent for the millionaire businessman with 2,000 hours in his log book is unlikely to be practical for a new pilot.

Join the AOPA (Aircraft Owners & Pilot's Assn), & take advantage of their many free offerings, like PIREPs on specific planes. EAA (Experimental Aircraft Assn) is also excellent, very interesting & educational magazines.

C.f.b Find access to a plane (aside from the above)

The below lists a little data on just a few of the hundreds of makes-models of planes that are available for Aero Navigator-pilots.

The abundance of factory built FAA certified lightplanes is overwhelming; especially used. Homebuilt offerings are even greater. It is certainly wise to learn as much as possible before considering any investment; be it purchase, partnership or club. Desires & goals will almost certainly change during the flight training process, & even more over the following months & years. The variety of planes is as diverse as the variety of desires. Some pilots prefer antiques or replicas of same. Some want just aerobatic, or biplanes. Others just small slow planes like the J-3 Cub, or a WWI replica biplane. Most prefer a very fast, long range plane, although many do not like to fly over 3 or 4 hours at a time. Like most activities, a person's preferences usually change during the various changes of training, & gaining experience. The options are nearly unlimited, especially among homebuilts. The author likes extensive avionics to provide more information &

redundancy for IFR; only likely to be practical with sole ownership. He also likes long range; so his plane had 50% longer range than most. Fuel stops reduce the utility of a plane. Many, of course, just want very high speed planes; not generally a wise choice. Even slower planes reduce travel time vs. cars, busses, trains & usually airlines.
One of the saddest non injury flying stories involved misguided priorities and one of the author's best friends through high school & into college; flew model planes with him, & took flying lessons at the same time, but decided that if he could not afford to fly a P-51 Mustang, it was not worth continuing. In fact, he may have been able to afford to buy & fly a Mustang at that time, but not necessarily safely. He never flew after obtaining his private pilot's license. Over the years, the pleasure & satisfaction that the author enjoyed by flying much slower planes than a Mustang has been enormous. Sole ownership was the most rewarding, but 3 flying clubs & flying 45 "types" were also rewarding. Hundreds of thousands of Americans have thoroughly enjoyed flying an enormous variety of types; or even only 1 make-model. Only a small minority have ever flown the P-51, or any other WWII fighters.

The author bought his first plane within a few months of receiving his private license. He nearly traded it for much faster planes twice within the first two years; which would certainly have been a major mistake. His second was much like the first, & carried his pilot-wife; with 2 small boys in a jump seat, which left little room for baggage. After his wife obtained her license in that plane, they began evaluating 4 place planes for the intended expansion. After 2 more children joined the family, it was decision time; they needed a 4 to 6 place plane. That plane, based on experience gained during several hundred hours of flying, coast to coast & all over the U.S., was wisely chosen, & served the family safely, reliably, inexpensively, & exceptionally well for 41 years. He'd never have chosen (nor could he have afforded) that plane with only 100 hours of flying time, but had he, it would not have been a wise choice at that time.

John Travolta owns & flies several multimillion dollar planes; more than most, but many other celebrities from all walks of life also fly at least one plane. There are many pilots who literally collect planes, & own several, or even hundreds. But thousands of pilots from all walks of life own planes; more than one might expect own several.

C.f.c Types of Planes Available & Cost:

Find a modern certified lightplane; new or used Piper, Mooney, etc.
Classic or antique (some are very fast, & still perform well & safely).
Certified planes from the mid 1940s; or some that qualify as LSA. Most sold very well when new, until the GI training subsided & the used trainer market bottomed out. Some are still popular, practical & safe.
Recently designed & manufactured LSA (Sportplane).
Replica
Homebuilt
War birds

The brilliant Wright brothers first successfully flew a powered plane in 1903. Any engineer today would have been proud to have performed such detailed & ingenious research with so little education & prior data for reference. Well educated men had failed before them. The cost must have been astronomical, also. WWI planes were also costly, but after the war ended these planes sold relatively cheaply. Experienced WWI fighter pilots returned to make a living by various types of flying, including instructing. They could more easily afford surplus planes like the very large, underpowered Jenny; the one that Lindy flew for his mentor & friend, to parachute from at an early air show. He jumped when the Jenny was unable to gain sufficient altitude, & broke an arm. As aviation matured performance improved, & new designs were marketed.

Over the years there has always been a used plane market. Paragraph B.f above on product liability insurance & safety explains the major reason for aircraft price inflation; in addition to the massive 2009 printing of un-backed money, which obviously causes inflation. As new plane prices increase the used plane market improves for sellers. Some designs are listed below, with prices on those that could be conveniently found. A little historical price info gives an indication of the inflation over several decades:

C.f.d 1947 Plane Values

The trigear Beech Bonanza was introduced in 1947 for a price under $5,000; the same as a surplus P-51 Mustang. The J-3 Cub sold used for $300. The Cessna 120 & 140 taildraggers were introduced in '46 & sold for $2,500 & $3,500 respectively. The series of planes that were made at the same time & now qualify as LSA sold for a little less.

From the mid 1930's to the late 1940s there were a variety of other excellent planes on the market, including Eurcoupe (or

Air Coupe; several names & company owners), the ever popular Piper J-3 Cub & several other less popular Pipers, Monocoupe (including one that Lindbergh owned, a 5 cylinder radial powered SBS high wing beauty; hanging in the terminal building in St Louis), Taylorcraft, Luscombe, Porterfield, the awesome 5 passenger 200+ mph all metal 450 hp radial powered Spartan Executive, the beautiful 200 mph Beechcraft Staggerwing (old material of construction & a biplane), a series of varied Aeronca designs, the fast & efficient Bellanca series that were soon upgraded, Culver Cadet & Culver V, several versions of Fairchild & Stinson, & Interstate Cadet.

A few years later the market stepped up to more modern all aluminum trigear planes such as the Mooney series, North American Nation (1 was owned by Barry Goldwater), fast little all metal Globe/Temco Swift RG 2 place SBS taildragger, Cessna 172, 182, & 210, which were introduced between the late '50s & early '60s. The Bonanza performed & sold very well as it continued in production for many years.

C.f.e Comparative Plane Values in 2000 - After Inflation

As time passed, the prices crept up. As of the year 2000 the above prices were approximately the following: New 172, $260,000; new Cessna 210, $500,000; New Bonanza, $600,000. The highly treasured surplus P-51 averaged between 1 & 2 million dollars, & continues to rise. The FAA registry showed 163 P-51 Mustangs as of 9-9-'09. AirVenture Oshkosh typically has over 50. The wonderful little J-3 Cub typically sells for over $35,000, while the great little Cessna 120 sells for about $2,500; same as when new.

Like pleasure boats, recreational vehicles & camping trailers, aircraft can be moderate in cost, or astronomical. Used airworthy lightplanes may be found for $1,000 (very rarely) to $800,000. More likely prices would be $15,000 to $50,000, with quite a few that top $100,000. Some engineers may enjoy buying basket cases & rebuilding them; in which case a licensed mechanic must be involved.

C.f.f Lightplanes on the Market in 2009

In view of the increasing cost of planes, many pilots search for used aircraft bargains. This does not necessarily sacrifice safety. A concern, though, is actual value. A plane with fresh engine overhaul is worth much more than 1 with half the engine life remaining; or near zero. A problem there is that the engine may have been abused; or the overhaul might have been done (illegally) poorly, or even dishonestly accomplished (less than proper part condition). Engine overhauls are very costly, so it behooves a person to find a disinterested reputable certified aircraft mechanic to evaluate both airframe & engine. A 2,000 hour expected overhaul life would last most pilots 20 years, so an engine with 1,000 SMOH would last longer than most pilots would want to fly that plane. A major overhaul of a 100 hp engine would usually cost about $10,000.

A used plane may have avionics that are obsolete; or scheduled for same. Occasionally the FCC requires an update that will obsolete older avionics, such as narrower frequency spacing. A mandated change of even a single navcom could financially devastate some plane owners.

A laborer who lived in California several years ago was quoted in an aviation magazine article. He earned precisely the national average income, lived in a typical medium priced home, supported a family of 4, & owned a very nice 2 place certified factory built lightplane.

For several decades pilots have built their own beautiful experimental / homebuilt planes of varied types & performance from plans or kits, for a moderate cost. Some sophisticated kits actually cost from $6,000 to over $100,000. Some home-built planes cost more than most luxury cars.

For a quick survey of used plane prices, pull up TAP (Trade-A-Plane.com), or barnstormers.com. It would be very informative. Since some planes are not well known, a trip to the airport may help; if nothing else, ask pilots who you meet there. Just realize that there may be fans there of planes that you'd never enjoy, & fans may exaggerate. The poorest handling, most dangerous plane ever designed definitely has some diehard fans, so don't base all of your advice on one person. Go to a Mooney, Cessna, or Piper, etc club gathering for a one sided view of that plane. The RV builders often rent a large hangar & share tooling. There may be a dozen or 2 RVs in various stages of completion. You may never hear a bad word about RVs in that group. Of course, it is a remarkable plane in nearly every respect. The local EAA chapter will usually have several flying homebuilts & some under construction. EAA headquarters can provide info on the nearest chapter.

The author highly recommends that anyone interested in learning to fly or buying a plane join the AOPA, & preferably also the EAA before searching for a plane to buy. The AOPA will send members PIREPS (pilot reports) upon request. Specs, performance & PIREPS may provide vital info to influence the decision of type to buy, since they include both negative & positive comments by objective pilots who have flown them. They also offer a title search, which is essential on used planes.

The best way to "overdose on planes" is to go to the undisputed greatest air shows in the world; AirVenture Oshkosh, at Oshkosh, Wisconsin. It is attended by more flying enthusiasts, from more countries than the famed Paris air show. It lasts 1 week plus 1 week end; always the week that includes both July & Aug. You will be overwhelmed, & learn more about planes than from any other source. Some describe AirVenture as "almost a spiritual experience". The cleanest property & nicest people you are likely to find at any event. Absolutely no trash on the ground. Mutual respect between locals & visitors. The locals rent parking & camping spots, & spare rooms to hundreds of strangers because even the University dorms cannot hold the motel overflow. When a major storm hit during the night, & flipped over 7 planes tied down (& anchored) just within 150 ft of the author's plane, the author & wife barely had time to stuff the sleeping bag into the back seat & buckle down to help hold the plane down. In less than 30 minutes, volunteer Boy Scouts came by to ask each person if they needed a place to stay; in case their tent had been soaked or destroyed. Locals who had no rooms to rent still offered rooms or living room floors to "needy Oshkosh visitors". A truly hospitable populace. If interested in going to AirVenture Oshkosh, investigate sleeping accommodations first; there is always a way, but it may involve camping out or sleeping in a car or plane. An advantage of flying into Oshkosh with IFR reservations is that they allow such planes in even after the field is closed, due to being overcrowded.

AirVenture Oshkosh has dozens, if not hundreds, of helicopters, antiques, classics, LSA, sailplanes, seaplanes & amphibians (even their own water landing site), ultralights, WWI & WWII replicas & some very practical, large, & fast designs; some that truly push the state-of-the-art. Also a few flying cars, man powered blimps, & even a jet powered tractor (18 wheeler power unit).

Local air shows often show dozens of planes of all ages & types; Livermore, CA has one air show per year that offers about 600 planes to look over. Dozens of airports all over the country have similar air shows.

If interested in a specific plane by NNo., or a certain model number, look it up on the internet under the "FAA Registry". If interested in a specific design, like the SE lightplanes listed below, pull it up there, too. The FAA registry listed planes that were registered as of mid 2009 to give an indication of the number of just a few models that are now registered (the top 3 listed qualify as sportplanes; LSA):

Taylorcraft BC-12D - 1,790 registered as of mid '09.
Piper J-3 - 5,472 registered.
Piper Vagabond - 349 registered. Wagabond is a copy that is not listed by FAA because each has 1 builder.
Culver Cadet LFA - 74 registered.
Culver V - 53 registered. (80 hp, 120 cruise)
Cessna 150 - 13,542 registered. (85 hp, 125 cruise)
Cessna 172 - 26,300 registered.
Cessna 182 - 16,150 registered.
Cessna 210 - 5,575 registered
Piper Cherokee 6 - 5,013 registered.
Mooney M20 series - 7626 registered.
Beechcraft G36 (one of many Bonanza models; hundreds are available) - 114 registered.

The cost of new certified (factory built) planes suitable for VFR could be as low as $40,000 or as high as $600,000 in 2009; $300,000 up for IFR equipped lightplanes. Jets & light twins (multi engined versions of SE lightplanes) are priced even higher.

The cost of used planes suitable for VFR could be as low as $8,000 in 2009. $20 - 30K is more likely, depending on needs & desires. Many top $100,000 used. IFR adds a few thousand dollars, even to used planes.

Homebuilts can be found for as little as a few thousand dollars, although some actually cost over $100,000. Newly designed Sportplanes seem to top $100,000. Very old planes that qualify as LSA include the wonderful little Taylorcraft BC-12D which was built in the 1940s & '50s. They now cost from $12,000 to $30,000 in "airworthy" condition. They cruise 95 mph on 65 hp & burn 3 gph. Still a safe & enjoyable plane to fly. Fuel capacity ranges from a 12 gal. nose tank to 24 gal. total with 1 or 2 small wing tanks. Steel tube fuselage & empennage structures with fabric cover. Usually a wooden wing structure with fabric cover; sometimes aluminum spar or ribs. The 65 hp Continental & Lycoming engines do not readily adapt to starters or generators, so must be hand propped. All of these planes are still flown in abundance, with respectable performance, safety & confidence.

Many more home builders start than complete a homebuilt plane, thus there are many "projects" on the market. Before buying a project a lot of serious research is required. Study the quality of workmanship on components that are completed. Documentation per FAA expectations? Cost & time to complete? Is plane a good safe design that will suit buyer's needs?

C.g Summary of Specs & Performance of a Few New & Used Lightplanes That Are Available in 2009, Along With Values of a Few

Pertinent details on a small sample of planes follows. Factory built (certified) planes, LSA, & homebuilts are included. Prices, where listed, except when stated as new, are for used planes as found on Barnstormers.com or Trade-A-Plane.com; Aug '09.

C.g.a Specification & Performance Code for Planes Listed Here:

The enormous diversity of designs & material of construction justify a few codes per the following, listed in sequence on each line of data:
1. Seating: Number representing total capacity, followed by "s" or "t" indicate SBS or Tandem
2. Material of construction:
T&F = tube & fabric (usually includes wood spars)
W = wood (nearly always fabric covered)
M = aluminum
C = composite; fiberglass or similar
3. Wing:
B=Biplane
H=High wing
L=Low wing
M=Mid wing
4. Basic Design:
C=Classic or antique
H=Helicopters
L=Lightplane
LSA=Sportplane
R=Roadable plane
S=Sailplanes
W=WWII or replica of same
5. Landing Gear Type: See Para C.d.a.g for a dissertation on merits of each.
Td=taildragger
Tr= trigear
A=Amphibian
M=Monogear
F or RG= Fixed or Retractable gear
6. No. = cruise speed
7. No.= hp (or # = lb thrust for turbojet)
8. Make &/or model (& details such as price range if justified)
X=N/A for that descriptor, or unknown

For a good compromise between function, safety & cost, buy an older certified plane that qualifies for the new light sportplane category (LSA). The (LSA) applies to a plane with somewhat limited performance & capability. It can still be quite a practical plane, depending on the pilot's needs & budget.

A private pilot can operate with full privileges only if the certified plane is "within license". If IFR equipped he can fly IFR; or likewise, at night if equipped for IFR & night flying.

Comments re good or poor performance, high maintenance, desirability, etc. are the opinion of the author; reinforced by those of many other pilots.

C.g.b Certified Single Engine Lightplanes

2s-T&F-H-LSA-Td-F-70-36-Aeronca C-3 wire braced 1934 high wing
2s-T&F-H-LSA-Td-F-70-36-Aeronca K 1934 high wing - looks much like a smaller T-craft
2t-T&F-H-L-Td-F-85-65-CHAMP 7AC & 7EC $25,000 - $27,500 (a fun 2 place tandem; but did not 2s-2t-T&F-H-LSA-2t-2t-T&F-75-65-Piper J3 Cub; a simple, low performance trainer with unusual features such as a split door; window hinges up & door portion hinges down. For some reason, most who have flown it, including the author, consider it exceptionally nice to fly. Nostalgia seems a large part of it, & it soon became a treasured, high priced classic & then antique.
2s-T&F-H-L-Td-F-95-85-Aeronca Super Chief - $32,000 (way overpriced; a SBS dog)
2s-T&F-H-L-Tr-F-103-108-Piper Colt $17,500 (2 place SBS; poor handling & performer)
compare with the Piper J3 Cub)
2t-T&F-H-LSA-Td-F-85-65-7DC Champ $29K
2s-T&F-H-LSA-Td-F-95-65-1946 Taylorcraft BC12D - $16,900 - $29,000 (95 mph cruise on 65 hp SBS; a jewel to fly) 1,200 gross allows larger engine or fuel without exceeding LSA gross limit. It can be fitted with 3 small standard fuel tanks (vs. usual 1 or 2 at most) & a Continental 0-200, 100 hp engine, this would probably be the best of all low priced LSAs; & cruise 115 mph for 600 miles.
2s-T&F-H-LSA-Td-F-80-65-Piper Vagabond, cute, but quite a dog; would be legal as LSA with 100 hp Cont for much better cruise; though not an efficient plane. Introduced in 1947. Short wing is inefficient & generally undesirable. See Wagabond below. Rare; fewer than 300 were built.
2s-T&F-H-LSA-Td-F-80-65-Wagabond is a homebuilt that is a direct copy of the Piper Vagabond (above). Wag Aero is a respected & reputable supplier of parts & plans; full sized planes & model planes. Being a homebuilt, it could be fitted with folding wings for trailering home, but with tanks full it would be difficult to fold; or avoid fuel spillage. Rare since very few were built. Ideal might be to find a project that could be completed with desired modifications. If buyer spends enough time completing it he will qualify for inspecting to save money over the years. Can ask mechanic for help if in doubt.
2s-M-H-LSA-Td-F-85-65-Luscombe - 65 hp is standard, & qualifies as an LSA.
2s-M-H-L-Td-100-85-Luscombe - $27,000 - 1947 90hp (some prefer this to T-Craft; the author does not). 85 hp is standard; does not qualify as an LSA.
2t-T&F-H-L-Td- F-1976-2000 Citabria_ - $24,000 - $82,000 (a later higher powered version of Champ; a popular aerobatic trainer)
2s-M-H-L-Td-F-105-85-1946 Cessna 120 &140 - $16,500 - $41,500 (a joy to fly; excellent performer; all metal except for wing cover; undisputed leader in its class, but too heavy for the LSA category)
2/3st-T&F-B-C-Td-F-105-225-1929 Travelair biplane; Lycoming radial powered. 2 open cockpits, but front 1 is wide enough for 2. Obviously a treasured antique. $170,000.
2t-T&F-H-LSA-Td-F-100-70-Porterfield CP-65, horizontal opposed engine. 1939 design.
2s-T&F-H-LSA-Td-F-105-70-Porterfield 35-70, radial engine, 1935 design similar to T-Craft.
2s-W-L-LSA-Td-RG-120-80-1942 Culver Cadet, “hot” (not for amateurs), per data found, plane listed for sale has 85 hp, so is faster. May qualify as LSA depending on stall & top speed, $24,900.
2s-M-L-LSA-Tr-F-115-90-Ercoupe (or Aerocoupe). No rudder pedals. Wheel controls limited travel elevator to prevent stalls & ailerons which are linked to twin rudders. Beautiful, but limited controllability. Impossible to “crab” to correct for crosswind, so it must be landed with drift. As long as crosswind is moderate it aligns itself with the runway upon touchdown, & all is well. Some versions qualify as LSA. Smaller engines are the norm.
2t-T&F-H-L-Td-F-105-100- Citabria; essentially the same as the Decathlon, higher powered version of Aeronca 7AC; popular for aerobatic training
2t-T&F-H-L-Td-F-120-185- Decathlon; modernized still higher powered version of Aeronca 7AC; popular for aerobatic training.
2s-C-L-L-Tr-x-125-Diamond DA-20-C1 Canadian design; high performance; modern plane powered by a conventional horizontal opposed aircraft engine. One of several Diamond models.
2t-T&F-H-L-Td-F-105-102-Interstate S-1B Cadet
4-T&F-H-L-Td-F-110-150-Piper Pacer - $19,000 - $28,000 Predecessor of the Tripacer; essentially same without Tr.
4-C-L-L-Tr-x-135-Diamond DA-40 turbo diesel power.
4-C-L-L-Tr-RG-210-2x336-Diamond DA-42 light twin turbo diesel power.
4-C-L-L-Tr-x-170-Diamond DA50 turbocharged
American Champion Aurora (more recent than most of above)
4-T&F-H-L-Tr-F-110-150-Piper Tripacer; trigear version of Pacer. Still inefficient, unpleasant to fly, & a poor performer.

2s-M-H-L-Tr-F-110-150-1966 Cherokee 140 - $26,000 (a poor performer & high maintenance)
4-M-H-L-Tr-F-110-180-1966 Cherokee 180 - $26,000 a poor performer & high maintenance)
4-M-H-L-Tr-F-150-235-1966 Cherokee 235 - $26,000-$59K (a poor performer & high maintenance)
4-T&F-L-L-Td-F-120-150-STINSON 108 $34,359 [$12,900 disassembled for restoration] (quite a nice plane; not compared with Cessna 170)
4-M-H-L-Td-F-120-145-Cessna 170 - $23,500 - $69k (an excellent plane, but not worth over $35K in author's opinion)
4-M-H-L-Td-F-160-230-1953 Cessna 180 - $55,000 (an excellent performer & load hauler)
5-M-H-L-Td-F-170-300-1952 Cessna 195A - $62,000 (a real jewel; large radial engine, throw-over wheel, cantilever tapered (chord) wing; worth two to 4 x this price). More like a multiengine plane cockpit.
1-W-L-LSA-Tr-RG-125-65-Mooney Mite low wing similar to the fine 4 place Mooney line; a real joy to fly, but rare. The author consistently cruised 1 in a flying club 145 mph vs. 125 book & same reported (by professional pilots & factory) cruise; by flying on step at normal power.
Other LSA planes dating back to pre-WWII days, & on to mid 1950s include some, but not all models of several makes, including Interstate, & Eurcoupe.
2s-M-H-L-Tr-F-120-100Cessna 150 $20 - 30K Justifiably the best selling trainer in history; excellent for XC, outstanding safety & maintenance record, & a joy to fly.
2-M-L-L-Tr-F-115-112-Piper Tomahawk. Nice trainer, but not safe for spins which are desired for serious training
2s-M-H-L-Tr-F-Cessna 152 - later upgraded Cessna 150 with larger engine.
2s-M-L-L-Tr-F-1971 CHEROKEE 140 - $28,000 -$32,900 (a very unsuccessful competitor to 150; for good reason)
4-T&F-H-L-Td-x-x-Maule; Tripacer look - except much better performer; specializes in off field operations
4-M-L-L-Tr -F-Cherokee 180 - $32,500-$95,000
4-M-H-L-Tr-F-135-160-Cessna 172 $37,000 -43,000 (145 & 160 hp standard; the best selling plane in history for 50 years+; outstanding, safe, most efficient plane per a "utility" index that was developed to rate overall performance; like all Cessnas, exceptionally reliable & low maintenance).. The 145 hp 6 cylinder Continental engine used in the 172 until 1966 was much smoother than the Lycoming 4 cylinder in later models; also easier starting, & had more torque than Lycoming, so would climb faster.
4-M-H-L-Tr-RG-145-160-Cessna 172 RG $37,000 -43,000 (145 & 160 hp standard; the best selling plane in history 4-M-H-L-Tr-150*-195-Cessna 172XP_(a factory souped up 172) used $89,900 (* personal experience shows that 160 to 170 is easy in the Hawk XP; why is book slower??).
4-M-H-L-Tr-F-160-230-Cessna 182 $62,000-$93,500 (undisputedly the best plane in its class; justifiably sold more than any in its class)
4-M-L-L-Tr-F-132-160-Piper Warrior-$305,000 new
4-M-H-L-Tr-F-RG-180-230-Cessna 182 RG; turbocharged pressurized versions available. Cessna is the world's largest producer of aircraft for good reason, & continues to lead the industry. The worldwide buying public simply believes that Cessna offers more utility, performance & safety for the money.
4-M-L-L-Tr-RG-185-225- Beech Bonanza B model (second model made; 1950) $40,000 to $140,000; former sounds like a steal.
5-M-L-L-Tr-RG-205-285-1965 Beech Bonanza, $140,000 for later Bonanza sounds like a steal. Many consider Beech to be the Cadillac of the air. Sound, very well made high performance lightplane. Old, but many consider Beech to be the Cadillac of the air. Sound very well made high performance fast low wing SE RG lightplane; place that was later stretched to seat 6.
4-C-L-L-Tr-F-178-200-Cirrus SR20, New $270,000. Recently became a serious, though minor competitor of the Cessna 182.
6-M-L-L-Tr-Rg-245-350-Piper Mirage-$1,200,000 new
6-M-L-L-Tr-Rg-300-500 turboprop-Piper Meridian-$2,000,000 new
4-C-L-L-Tr -F-213-310-Cirrus SR22 4 place SE FG recently became a serious, though minor competitor of the Cessna 182.
4-C-L-L-Tr-F-RG-252-310 - Cirrus Turbo; high performance carbon fiber, new $380,000 with Turbocharged engine.
4-W/M-L-L-Tr-RG-130-150-Mooney M20 series; $39,000 for '64 to 1989. Offered for many years
4-W/M-L-L-Tr-RG-140-180-Mooney M20 series
5-M-L-L-Tr-RG-240-310-Mooney M22 series turbocharged, pressurized cabin, up to $300,000 for 1989 up. One version cruises a remarkable 278 mph.
4-M-L-L-Tr-RG-Commander 115 by manufacturer of the famed Aero Commander light twin
4-M-L-L-Tr-RG-158-200-Piper Arrow, aimed for complex plane training. $434,000 new.
6-M-L-L-Tr-F-150-300-1967 Piper Cherokee 6 300 Lance 6 place• $55,000 (not a good performer; poor handling; high maintenance). Same cruise as Cessna 206, but higher stall. Higher power Lycoming vs. easier starting & more reliable Cessna 206 Continental engines which are more fuel efficient than the Lycoming engines.
6/8-M-H-L-Tr-F-160-285-1968 Cessna U206 - $88,000 (the best 6 place FG workhorse on the market for decades).

4-M-M-L-A-RG-145-200-Lake 200EP amphibian; an exceptional amphibian in the air & on the water.
4-M-M-L-A-RG-150-250-Lake Renegade amphibian; as above. Later model powered by 300 hp
6-M-H-L-Tr-RG-190-285- RG-1968; for sale a1977 Cessna 210T/Centurion - $159,900 (the fastest 6 place plane for decades; even toped the famed & excellent Beech Bonanza; outstanding reliability. A safety factor is that its landing gear can be lowered at much higher speed than most RG planes; a great safety feature for quick slow down after unintentional over-speed in turbulence or heavy IFR. This provides an immediate increase in drag to decelerate in the event of partial loss of control under IFR conditions). Also available pressurized.
13-M-H-(L)-187-675-Cessna Caravan passenger / cargo hauler $1,300,000. Used extensively by UPS, Fed X, small airlines, corporate aircraft, bush flying (off - field). At $24,000 per year for insurance & 55 gph it's obviously not a poor man's machine.
6-M-L-L-Tr-RG-200-310-Piper Malibu Turbo pressurized plane. Low crosswind component (17 kts) capability, for some reason.
6-M-L-L-Tr-RG-415-SE jet-Piper Jet Fast Turbo Jet-pressurized plane. $2,200,000.

C.g.c Certified Light Twin Engine Planes (a small portion of those available)

Note that a much wiser choice would be a SE vs. ME plane until both the need & experience justify such a large step up. Flying a light twin without several hundred hours of flying experience, including an instrument rating, & absolute confidence & comfort under IFR conditions is unwise.

4-M-L-L-Tr-RG-Piper Apache light twin; slow & poor performer for a light twin.
6-M-L-L-Tr-RG-Piper Aztec C light twin; much better performer than Apache
6-M-H-L-Tr-RG-190-2x210-Cessna 337 tandem (in-line engines) light twin, fast & reliable, but unpopular
4/6-4/6-M-L-L-Tr-RG-245-2x260-Cessna 310 light twin, fast reliable very popular light twin, fast reliable very popular light twin
2s-M-M-L-Tr-RG-360-2x1,025#thrust-Cessna T-37B Cessna USAF jet trainer; very small; not good for long range XC like typical jets
4-M*-L-L-Tr-RG-180-2x160-Beech 76 Duchess light twin (* indicates less desirable bonded Aluminum vs. rivets)
4/6-M-L-L-Tr-RG-300-2x360-Turbocharged-Beech 60 Duke light twin; Lycoming engines are normally hard starting; especially in high temperature conditions, but those used in this plane uses Lycomings that don't run well at high temperatures (per AOPA PIREP).
5-C-L-L-Tr-F-x-x-Diamond D-JET turbojet light twin; obviously very fast. Carbon fiber in composite.
5-M-L-L-Tr-RG-481-2xturbofan-Cessna Citation; very practical since it can be flown by a single pilot off of very short runways & is one of the fastest BizJets made. 5/7-M-H-L-Tr-RG-Light twin; many variations.
4-M-L-L-Tr-RG-x-x-Commander 500
6-M-L-L-Tr-RG-197-2x220-Piper Senica $800,000
7/9-M-L-L-Tr-RG-240-2x380-Commander 680 light twin, 1 tank in fuselage rather than usual in wings
7/9-M-L-L-Tr-RG-285-2x575shpTurboProp-Turbo Commander light twin
7/9-M-L-L-Tr-RG-450-2x2,850#Thrust-Jet Commander 1121 light twin.

C.g.d Roadable Planes (A Plane in Every Garage)

A goal since 1918 per the CEO of the Terrafugia Aerocar; 1 of the recently developed & apparently very successful & beautiful roadable planes. Not many planes may be placed in a garage, but the number of designs is growing rapidly.

For nearly as long as the author can recall there have been occasional announcements, usually in magazines similar to Popular Mechanics (an excellent magazine), of a "wonderful new fast, simple, inexpensive roadable plane. Nearly everyone would, of course, own 1. Most as sleek & beautiful as a P-51 Mustang, though smaller. None have been totally successful; fewer than 5% have ever flown. The author & his fiancée (now wife) saw the original Aero Car at the Olathe Naval Air Station at an air show many years ago. It was very impressive, but not a very good performer (nor are the best that have ever flown). The large tail cone could be disconnected, the wings folded onto it, & left at an airport so occupants could visit off field, & return. Or, if enroute weather was bad, towed down a highway until past the bad weather, & then flown home. It is actually still flying.

With the advent of the ultralight, experimental (usually actually homebuilts), & more recently the sportplane planes, roadable & towable planes, & home stowage have become more of a reality. Sailplane wings have nearly always been removed for stowage, & always have a trailer for recovery in cases where the pilot failed to make it to a runway. Many ultralights are intended for trailering home to avoid the cost of hangar rent, and some homebuilts were designed for trailering. Even fewer can be driven home; are roadable. There are several promising roadable planes that started undergoing flight tests in ‘08; others nearing that point.

There is another possibility that solves part of the “plane in every garage” problem. Thousands of housing developments all over the U.S. have their own runways. The Houston area has several such developments. A hangar next to the house is commonplace, & even very functional.

2s-C-L-LSA-Tr-F-125-100 (Rota)- Remos; Semi roadable (trailerable) designed & manufactured in 2000 in Germany. Folding wings permit trailering to avoid hangar rent, cruises as low as 2.3 gph. Sleek & attractive. $130,000 new with good avionics. Many actively fly around Europe.
2s-L-LSA/R-Tr-F-115-100 (Rotax)-Terrafugia Transition is a beautiful highly streamlined roadable plane that seems to offer a great deal of potential; partly because it can actually be driven home & sheltered in a standard garage. Being designed & flown by a team of MIT Engineers. 115 mph cruise on 100 hp Rotax engine. 51 mph stall, 460 mile range, 5 gph (27 mpg equivalent flying), 20 gal fuel capacity, 30 mpg on road, 2 place, automatic wing folding, glass cockpit, $194,000 projected price as of Aug ’09.
2s-H-R-Tr-RG-x-x-Voltane; a reasonably sleek possible upgraded of Molt Taylor’s 1950s era (still flying) Aerocar seems to have a bright future as an aerocar. It flew successfully in ’08. Resembles the Cessna 337 Skymaster tandem twin without the front engine. Has long pointed nose. . Price & production plans unavailable as of mid 2009.
2s-M-H-R-F-4-110-143-Molt Taylor’s Aerocar pusher, inverted rudder-fin; V-elevator, developed & flown during the late 1940s; tailcone removes to be towed home or past bad weather, still flying. Offered moderate performance in both modes. Still operational.
2s-M-H-R-F-4-110-150 wheel-Fulton Aerocar,; tractor, conventional empennage, tailcone removes to be towed home or past bad weather; 1948; still flying.

Several additional aerocars are under development; some are even undergoing flight testing.

C.g.e Affordable Planes:

The new LSA (light Sportplane category) should “nominally” indicate lower cost than fully certified planes. Actually specially designed new LSAs are quite expensive compared with many new comparable certified lightplanes, & especially higher priced than the older used factory built planes. For the frugal, there are many moderately priced makes & models of older certified lightplanes that qualify as a sportplane. These planes use older technology, but are quite practical & perform very well & safely.

The Cessna Skycatcher is one of several LSAs that was produced & professionally tested by a team headed by a leading small plane designer-manufacturer. They even have a web page: www.cessna.com/single-engine/skycatcher-specifications. It was designed to push the limits of the Sportplane category specifications & performance. It stalls at 51 mph, cruises 131 max, for up to 541 miles on 24 gal of fuel; powered by a 100 hp engine, & costs $108,000 new. The Skycatcher shows a great similarity to the Cessna 150, which was the fastest selling lightplane for many decades during its exceptionally long production life. Some of the other new LSAs are comparable in all respects, & with similar price tags. If made by Piper, Mooney, or other American manufacturers of certified aircraft they would most likely be as thoroughly designed & tested as their certified line.

Most LSAs are very specifically designed to provide the most utility, speed, etc. for the new category. The Skycatcher range of 541 must include a reserve. An “official range spec” is usually based on an unspecified moderate cruise. See Note 1 below. Assume 125 mph cruise & 1 hour reserve. In this case, range to dry tank would be 541 + 125 = 666 miles. That computes to 666 / 24 = 27.75 mpg. With the stated 346 lb payload, with full fuel, & a lightweight pilot & passenger, an aux fuel tank could be added (if approved) to increase fuel load by 15 gal. That would increase range from 541 to 957 + a 125 mile reserve. So this particular LSA might possibly fly 900 miles nonstop in zero wind.

Note 1: Range may be traded for speed in any plane. An example is the 195 hp, ’81 Cessna Hawk XP. This is illustrated for a cruise altitude of 8,000’ & 30°F, the 172K the performance is:
TAS cruise - % power- range is:
147 - 74% - 610;
137 - 65% - 773;
119 - 55% - 858.

This data is conservative, since Cessnas tend to outperform official releases. Manuals are based on flying at max gross weight; in this case with 66 gallons of fuel in the tanks, but enough fuel upon landing to fly an additional 45 minutes; a 45 minute reserve. The Hawk XP is a 4 passenger plane, but can be fitted with a jump seat in the baggage compartment, which is capable of carrying 200 lb. The above data proves that it is actually sometimes faster to cruise slow enough on long flights to avoid a refueling stop.

Some new LSA are amateur built. Most take full advantage of the allowable limits.

There were, as of mid 2009, several dozen LSA manufacturers, & over 100 different models. Many are not expected to survive in the marketplace, but quite a few will.

A current driver's license is required to fly LSA, but a flight physical is not required. A LSA pilot may not have failed his last flight physical, however. It is obviously prudent to fly only if physically fit, & not susceptible to any potentially disabling condition, such as being at risk of passing out. Self grounding is also mandatory for pilots possessing a current medical in the event of temporary condition that would prevent him from passing a flight physical. The author had a temporary eye problem on 2 occasions. The first with the entire family in the Cessna, midway down the East coast on a long vacation. A large green fly bite in Maine progressed until safe landings were impractical. His pilot-wife took charge & flew it down to the Florida Keys, along the Gulf coast, & back from Corpus Christi to New Mexico. The second time resulted from an eye injury that required surgery. He was amazed to find that with a qualified pilot in the left seat (to keep it legal) his landings seemed flawless. Since he looks over the nose of a trigear, & over the side in taildraggers, he probably would have had difficulty in a taildragger. The fact is that depth perception is only good to about 50 ft, so there is a major difference between looking over the nose vs. the side.

A LSA that "pushes the limits" of the new category is actually considerably faster & more practical than the family car. A typical road trip between 2 points is 10% further than flying; but the spread is often much greater. A trip that the author & his pilot wife have made many dozens of times to allow her to buy Indian Jewelry for her world famous shop is only 900 (usually nonstop) miles by air, vs. 1200 miles by road (nearly without a fuel stop with the Suburban's large fuel tank & great mpg, but a motel stop is necessary). Instead of a night in a motel each way, & 2 days of driving (even with 80 mph speed limit in much of TX), they flew a moderate speed lightplane from the SE side of Houston TX to Gallup, New Mexico in a few hours, & still had half a day to shop. The LSA that maximizes the allowed performance of 138 mph at full throttle would probably cruise faster than 125 mph at 75% power, or 115 at 65%. At 125 the 900 mile trip would take 7:15. The 1200 mile Interstate highway drive takes nearly 20 hours including some city traffic. The LSA should require at least one fuel stop for such a long flight. A fuel stop can be completed in as little as 15 minutes, including landing & taxiing, when it only requires 15 or 20 gal pumped by a pump that is intended to deliver hundreds of gal. of Av-Gas quickly.

The LSA limitations do not include any design evaluation or flight testing requirements, so some "may not" be as safe & predictable as the LSA offered by established manufacturers. Most reputable manufacturers use the extreme analyses & testing that they did for their certified planes.

Planes flown by sportplane certified pilots are restricted, & limited to the same values as the LSA planes, per the following: 1320 lb max gross weight, 51 mph max stall speed, 138 mph max level flight speed at full power, 2 passenger max, single engine, FP or ground adjustable prop, unpressurized cabin, FG (except for sailplane or amphibious seaplane), must meet FAR Part 103, have a FAA registration number, limited to daytime VFR only, at or below 10,000' (except in high mountain country). LSA may be experimental-homebuilt or factory built.
A LSA "maintenance certificate" can be obtained so a Sportplane pilot can measurably reduce maintenance expense.

If a 2 place plane will satisfy a pilot, the major disadvantage in a sportplane is the restriction against IFR. That is not a safety issue, since legitimate inadvertent IFR is always tolerated by the FAA. A LSA can actually contain a large compliment of avionics, including IFR capability. It may not, however, be flown IFR unless the installations are approved, & the pilot is rated for & current in IFR. The LSA is a very practical & enjoyable way to travel; or simply to fly.

Most LSA will actually transport 2 people cross country several times as fast, & for less money, than most cars. In most of the U.S., especially Eastern U.S., the speed limits drop to a fraction of the cruise speed of most LSA.

For a good compromise between function, safety & low cost, buy a certified plane that qualifies for the new light sportplane category (LSA). The (LSA) applies to a plane with somewhat limited performance & capability. It can still be quite a practical plane, depending on the pilot's needs & budget.

Many older certified planes, largely from the 1940s, qualify as LSA. Most from that era used "earlier" construction materials; typically "tube & fabric", & were low powered, & low speed. "T&F" (tube & fabric) is short for a popular early era airplane method of construction; 4130 aircraft alloy steel tube (still earlier; a lesser alloy) truss type fuselage frame & empennage, with wood spar & ribs for their wings, & fabric cover for all. Sheet metal nose bowl & cowl, & spruce formers & fairing strips completed fuselage fabric support. A few utilized metal spars & ribs. The famed Piper J-3 Cub & vintage T-Craft (Taylorcraft), like other older LSAs, are fully certified & well proven to be safe & functional. The Cub is truly a joy to fly, but only cruises at 75 mph. The Cub, & to a lesser extent the T-Craft, were often fitted with engines up to 200 hp & flown extensively in air shows doing aerobatics to amaze the crowd. The T-Craft cruises 95 on 3 gph; netting the equivalent of more than 32 (35) mpg. An upgrade to a 100 hp engine should produce a cruise near 115 on 4 gph; 29 mpg (32). The new Cessna Skycatcher LSA averages 28 (31) mpg. A flight between 2 points is usually 10% shorter than a freeway between the same 2 points. Correct for the shorter flight distance, & the equivalent mpg becomes the values shown in parends. Cost of fuel varies almost daily, but if $3.00 / gallon the fuel cost on a trip would be about 10¢ / mile; $10 for a 100 mile flight. Most classic planes that qualify as LSA sell used for $12,000 to $25,000. An exception is the ever popular J-3 Cub that is loved by most pilots; especially those who have flown one. $35,000 is not uncommon for a J-3. Current prices of a few certified LSA are found in para C.d.a.c. Some cars do top these mpg figures, but at great risk. The federal agency that tracks highway safety reported in discussing the 2009 change in CAFE standards that since the implementation of the CAFE standards 55,000 **additional people** have died in automobile crashes **because** of the CAFE standards. They also report that the 2009 revision to the standards will result in an **additional** 900 deaths per year in the US. Some Texas freeways have an 85 mph speed limit; still far below the LSA max cruise. The author lived in a Philadelphia suburb for nearly 2 years. It took him half an hour in light traffic to travel between home & the airport. Flying it took 2 to 3 minutes. Visibility was often so poor that he lost sight of the runway that was only 1/8 mile to his left in order to be able to shoot landings. Weather there was frequently so bad that most VFR flight violated FAA minimums, IFR approaches were made only by dropping below legal ceiling minimums; quietly accepted by the FAA & most users. Neither wise nor pleasant. Quite a shock after the 24-7 100 plus visibility of New Mexico. Not good, but flying in Germany routinely involves violating IFR minimums.

Most Sportplanes are powered by engines with less than 100 hp; many 65 hp or even lower power. The latter could burn as little as 2 gph ($6.00 per hour at above cost); some "standard certified" training planes burn 5 to 20 gph ($15 to $60 per hour). In some parts of the U.S., auto-gas is readily available at the airport, sometimes for a savings of 30%. Many New Mexico airports offer auto-gas. If not available at the airport, & if allowed by the FBO, a simple home-made refueling system will work very well, but do not forget that gasoline explodes if only slightly pressurized. For a time, after the introduction of "100 low lead Av-gas" caused many engine failures around the country, the author transferred up to 35 gal. (usually adequate for the 60 gal fuel capacity since it's not recommended to run tanks too low) of auto gas per fuel-up using redundant proven low pressure (inches of water) air regulators that were plumbed in series to slightly pressurize a 35 gal. pressure vessel. It certainly beat the 5 gal cans used to manually refuel the same plane in Mexico. His engine was very sensitive to a newly introduced Av-gas lead content until the lead content was reduced, & Al Hundere's Alcor TCP was developed to neutralize lead content sufficiently to eliminate spark plug fowling. For a year, before TCP was introduced, the author was forced to clean his 12 plugs every few weeks while commuting across Houston daily.

The cruise speed for these older certified planes that qualify as LSA range from 65 to 110 mph, with stall often below 40 mph. SBS vs. tandem seating are about equal. There are several different designs that were made by, Eurcoupe, Porterfield, Interstate, 65 hp Luscombe, Piper, Aeronca, & Taylorcraft, to name a few. The latter 4 dominated when new, along with the 85 hp Luscombe & Cessnas that are too heavy for the LSA. The 85 hp all metal Luscombe & Cessna 120, are certainly the best of the planes of that vintage in most respects, but exceed the LSA gross weight limit. Some are quite scarce, but most are actively flying well into the millennia. Some pilots prefer the Eurcoupe; more prefer the Luscombe & Taylorcraft (all 3 qualify as LSA). The only vintage all metal planes that qualify as LSA are the Eurcoupe & 65 hp Luscombe.

The official limits for the LSA are based on original factory specs. Gross, for example, cannot be downgraded, even though at 1320 gross the Cessna 120 would still outperform, & carry more payload than most vintage certified LSA do. The most highly treasured plane from that era is the wonderful little Piper J-3 Cub. The T-Craft & Cub have been fitted with grossly larger engines, & proved to be formidable planes for air shows, aerobatics & just plain "fun", even into the 2000s.

The certified sportplanes fully qualify for operation under the privileges of a private pilot. A private pilot can operate with full privileges only if the certified plane is "within license". If IFR equipped he can fly IFR; or likewise, at night if equipped for IFR & night flying.

Many homebuilts qualify as LSA. Cost of homebuilts varies more widely than certified planes, for a variety of reasons.

C.h.a Homebuilt - Experimental Planes

C.h.a.a Amazing Number of Types of Experimental Planes

The term "experimental" once applied to planes used for testing before certification, & very strict limitations applied, including limiting occupancy to essential crew members. It was relaxed to include homebuilt planes with fewer restrictions. Since it now includes warbirds, it seems more appropriate to retain the word homebuilt for that group of planes. Most prefer the term experimental, however.

Homebuilts may be found in the form of plans or kits from which to build a homebuilt, or on the used plane market.

There are far too many homebuilt designs to list in this course, but there are a few directories that list many. The below mentioned Kitplane listings are overwhelming & informative, & list hundreds of plans & kit suppliers. The annual Kitplanes list of most available homebuilt planes is invaluable to the fledging flying enthusiast: The variety is enormous.

Trade-A-Plane & Barnstormers; found on the Internet, list hundreds of planes of many types for sale.

Sport Aviation (EAA publication) & the AOPA Pilot magazine are also excellent.

The type of homebuilt designs is endless. A few examples of options:

Aerobatic
Amphibians
Autogiros
Helicopters
LSA
Replicas of exceptionable planes like the Wright Flyer.
Roadable
Sailplanes
Seaplanes
Trailerable
Ultralights
Unique & beautiful fun planes
Unique & beautiful fast planes
Unique & ugly or funny looking planes
Unique work horses
Very practical, large, & fast designs.
WWI & WWII replicas,

There is now even a “homebuilt” Spaceship; SpaceShipOne. Test pilot Michael Melvill (age 63) literally rocketed into suborbital space (337,500’) September 29, 2004; & glided to a landing at Mojave Calif after an unplanned “victory roll”. Burt Rutan was, of course, the designer. SpaceShipOne was actually carried to 50,000’ by a Rutan designed mother ship. It did qualify for a $10 million prize; a competition much like the 1 that Lindbergh won his $25,000 prize in. Rockets boosted the speed to 2,400 mph (Mach 3.2).
The famed, amazing one of a kind record breaking “round the world nonstop” Voyager was in a sense a Homebuilt design, in that it was the creation of the world famous homebuilder & designer, Burt Rutan.

There was even one homebuilt that replicated the flapping wing flight of a bird.

The man powered Gossamer Albatross English channel flight was also amazing. The author had the opportunity to “lift” the wing tip as the plane was being disassembled. He was told the obvious; it was very light; 4 lb.

A wide variety of homebuilts have made very long flights; across the Atlantic, etc., and quite a few have flown around the world.

The extremes of homebuilts include tiny single place planes so small that they can nearly be picked up by the pilot, & he can nearly reach the wing tips from the cockpit; to some so large that they are amazing. The author & his wife had the opportunity to walk around & look into the massive flying camper that was intended to take quite a group to an isolated lake. The cabin was approximately 8 ft wide & 20 ft long. Each of the two engines was 350 hp. They also had the unique privilege of taking off behind that plane from the 6,000’ elevation Santa Fe NM airport. They both climbed & turned nearly 180° to headings that differed by about 20° & climbed several miles apart to 10,000’. Climb speed appeared to be in the vicinity of 110 mph & ROC seemed to be only about 200 fpm.

A homebuilt that was built for very high speed cross country flying is generally not a good trainer; nor a good plane to fly without a few hundred hours experience. It would most likely have a high wing loading, & stall characteristics that leave something to be desired. Van's Aircraft's line of safe, fast, low stall all metal 2 place low wing planes would be an exception & a good starting point, if high speed is important. A much better plane to start flying would be a slower plane with good characteristics, such as the J3 Cub or Cessna 150. So would some of the newer, slower well proven designs intended for training.

The original material of construction became T&F (steel tube fuselage & empennage, wooden wing structure, & fabric covering). T&F is actually even better today than it was in the 1920s, thanks to improved glues & varnishes, & weatherproof paints for coating fabric.

The trend shifted to aluminum, & much later, for some, composites; usually fiberglass or variations of same.

Composite planes built from scratch will not generally have the benefit of an autoclave. Thus if the operational or storage temperature exceeds the construction - cure temperature, the plane will lose strength & may possibly be unsafe. This is especially true of composite designs that are tied down & exposed to the heat of the sun. The problem was first noted by Canadian homebuilders who often did their lay-ups in cold garages. Not all kit built planes include autoclave cured structural components. If not, it would be wise to find another design. Another disadvantage of composites is that the only way to assure continued structural integrity (except for obvious cracks) is to load to near the design load limit. But to do that, the most practical way is to invert the entire plane & load the lower surface of the wing with sand bags. While serving as the "composite expert" for a division of one of the largest manufacturers in the U.S., the author decided that his preference for aircraft structures would remain Aluminum.

The only disadvantages of aluminum appear to be corrosion, & lack of fatigue limits; S-N data; stress - Number. of cycles. Steels have specific fatigue limits, but aluminum does not.

A good example, from Marks handbook for MEs: Fatigue obviously depends on stress as well as the number of cycles at that stress. SAE 3420 quenched & drawn at 1,200F, cycled repeatedly at any high stress will fail eventually.

The Marks HB shows absolutely no fatigue failure below 67 kpsi, even after 100 million cycles. The curve is nearly flat down to approximately 1 million cycles; at very slightly higher stress. At 70 kpsi the fatigue limit is approximately 250,000 cycles. At 80 kpsi the fatigue limit is 100,000 cycles. At 95 kpsi the fatigue limit is approximately 30,000 cycles. That works well for easily predictable machinery. The engineer will simply design for a low enough stress to stay below the limiting no. of cycles. But for aluminum planes it would be nice to know a safe stress level for a cycling load. Lightplane props are highly stressed & subjected to an enormous no. of unpredictable cycles. The prop makers know this, & greatly over-design them, so they are safe. A FP prop never fails. More heavily stressed CS props do, but it too, is extremely rare. But airliners are subject to, & track pressurization cycles. The fuselage is a pressure vessel that could fatigue & fail. That risk is nearly eliminated by use of NDE; careful fracture examination during routine inspections. The NASA zero-g aircraft was limited to a specific number of hours in the zero-g mode of operation; somewhat of a roller coaster, with far more stress reversals than the norm. That limit was increased several times over the years; undoubtedly after very serious analyses & skin examinations. All airliners should be monitored to track number of pressurization cycles, & relate that to known safe operation; or structural failures. Lightplane cycles much less than an airliner, but because it is such a popular "work horse", 10,000 flight hours is not uncommon for a typical Cessna 206, it would seem prudent to shop for a 3 or 4,000 hour 206, if in the market for one. Smaller Cessnas typically have less than 5,000 hours, & are structurally as sound as the 206.

C.h.a.b Material of Construction:

Most designers, as of '09, tend to build with the "modern" material; composite, but these materials are not as predicable or reliable as T&F, wood, or metal (aluminum). Those sold as kits come with pre manufactured composite structural components. Structural composite components are usually "cured" in an autoclave, which provides adequate & consistent strength. If these components are not cured in an autoclave they should be avoided. Plans built composite structures are certainly not a wise choice because curing in a garage leads to questionable strength, as discussed elsewhere. If predictable components such as wood or aluminum provide necessary structural components are used, they will be safer & much more predictable.

Homebuilt-Experimantal Planes						Plans Only							Fig. C-1		
Seller	Applic-ation	Cruise-Stall	Max Dist.	HP	# Pas	Empty-Goss	type wing	Land Gear	Mat'l of Constr	LSA	Build hours	Cost of Plans	Total Cost	# flown	Ref
Arcolite	SAT	90-40	290	65	1	450-720	T	Td	T&F	Yes	2000	$125	$8K	1	
Cassagnes	ReplB	120-45	260	140	2T	1023-1575	L	Td	T&F	No	5000	$800	$10K	1	1
DCS Teenie	T	110-48	300	65	1	310-590	L	Tr	M	Yes	800	99	8K	300	
Fisher	T	55-26	210	28	1	254-500	H	Td	W	Yes	600	375	N	325	
OspreyGP4	XCB	240-65	2500	200	2	1240-2000	L	Tr	W	No	3000	385	50K	37	2
Pietenpol	T	80-40	140	60	2	520-1040	P	Td	W	Yes	1000	185	8K	600	3
War Corsair	Repl	135-55	460	100	1	600-900	L	Td	CMW	Yes	1500	265	22K	112	
Homebuilt-Experimantal Planes						Kits Only						Kit cost			
Ace A/C	AT	90-35	400	85	1	575-950	P	Td	T&F	Yes	1500	35K	75K	376	3
A/C Deigns	SXCB	235-76	2530	300	6	2200-3800	H	TrR	C	No	3000	95K	300K	7	4
Alisport	AST	56-40	N	N			S	M	C	Yes	350	50K	55K	2	5
AmphA/C C.	ASCXT	103-34	580	100	2sbs	695-1320	B	WTgR	see #6	Yes	600	29K	80K	91	6
Better Half	T	70-35	230	60	2sbs	385-900	P	Rd	T&F	Yes	1500	3675	11K	1	7
Comp Air	ASXC	284-71	2531	660	8	3800-7200	H	Tr	C	No	3000	200K	N	1	8
Comp Air	ASXC	375-71	2000	#	10	5.9-10.9K	L	Tr	CM	No	2500	500K	N	1	8
CreativeFlite	SXC	207-54	1750	2x	4-5	1870-3200	S	TrR	C	No	750	125K	300K	1	9
Falconair A	P-51rep	185-60	575	200	1,2T	1420-1985	L	TdR	W	No	2500	30K	60K	1	
Glasair	SXCB	278-67	1640	300	2	1675-2500	L	TdR	C	No	3000	51K	150K	250	
Hummel	T	115-38	350	37	1	300-550	L	Td	M	Yes	1200	12K	18K	120	10
Lancair	SXCB	225-65	1550	310	4	2000-3200	L	Tr	C	No	1200	90K	300K	55	
Lancair	SXCB	387-70	1320	750	4	2500-4300	L	Tr	C	No	1200	250K	800K	1	
Morrison A	SXCB	206-62	1660	400	6	2197-4500	H	Tr	C	No	1500	115K	300K	1	
NVQuestair	SXCB	275-68	1150	310	2	1300-2000	L	TrR	M	No	3000	69K	175K	50	
Hiperlight 8	T	60-27	210	28	1	247-500	B	Td	T&F	Yes	150	16.9K	20K	600	
Hiperlight 9	T	85-39	350	80	2	360-81	B	Td	T&F	Yes	300	25K	35K	25	
Vans RV-6	SXCB	208-58	900	200	2sbs	1080-1800	L	Td	M	No	1500	20K	55K	800	11
Zenair 640	SXCB	150-47	590	180	4	1147-2200	L	Td	M	No	1250	29K	60K	15	12

Application: S=sleek, XC=good XC, B=beauty, T=toy, Repl=replica. Seating: T=tandem,SBS=side by side
Type wing:H=high, L=low, B=biplane, T=tri-wing, F=folding, S=shoulderwing (midwing).
Land Gear:Td-taildragger, Tr =tricycle, R=retractable, W= water (usually amphibian), M= 1 wheel.
A/C=aircraft. N=N/A or not available. Many numbers are rounded off.
Ref 1=open cockpit beauty; 2=sleek & fast beauty; 3=Pietenpol & Baby Ace are sound & old open cockpit; Ace a beauty with enclosed cockpit; 4=Replica of Cessna 210; more beautiful. 5=Several beautiful sailplane designs; no power, or gas or electric. These a mean of several; # built ranged form 1 to 25; 6=Amphibian A/C of Canada; beautiful amphib., Mat'l CMT&FW. 7=nice little half VW (2 cyl) desigs by Leonard Milholand, 8=Comp Air; 2 of several nice fast designs that seat 4 to 11; most over 7.# indicates turbojet power of 3500#. 9=attractive twin engined pusher; 160 hp each. 10= Half VW engine included. 11= an exceptionallysound, all metal. 12=One of a nice series of varied designs bya Canadian who moved to Mexico Missouri.

ENGINES for Homebuilts !!!
Engines include the old favorites; most proven & best ever made; Continental & Lycoming. But also a well proven Rotax & VW. Jabiru seems good. Subaru & Hondas are neither safe nor reliable.
Big Chevy engines are great whjen you want lots of power & reliability, but an auto negine convsion is a complex & demanding task.
Old radials are beautiful & reliable, but not up to modern Continental & Lycoming, excet for looks. Fig C-1

Fig C-1 Homebuilt Planes

Kitplanes & Sport Aviation (EAA publication) are excellent sources on availability of designs, & construction procedures. The Dec '08, & Jan, Feb & June '09 Kitplanes show a variety of homebuilt plane designs that are available. The listings include plans & kits; for copters, ultralights, sailplanes, electric powered planes, LSA, planes designed for just plain fun flying, aerobatic planes, fast 2 place XC planes, fast 4 place XC planes, long range XC planes, turbojet, turboprop, very large cargo haulers, very large people carriers. Includes lots of turboprops; one 11 passenger. One 10 passenger turbojet that cruises 2000 miles at 375 mph. One Kitplane issue includes 320 LSA; another 96 LSA; another 458 helicopters; another 219 LSA. Many of the listed designs have web pages containing a wealth of information.

Browsing the above Kitplanes for just a few interesting designs resulted in a table listed as fig C-1.

A few of the many certified lightplanes & LSA on the used plane market were found on Barnstormers on 1 day, mid 2009; many designs are represented on Barnstormers & TAP.

There are literally hundreds of designs to choose from. Some would qualify as Sportplanes, & many would be suitable for training. It would be advisable to find 1 that has enough "history", including number of that design flying, so that a good safety record will be meaningful.

None of the aerodynamic or structural design evaluations, or flight testing requirements of certified aircraft, are required for homebuilts, so they are not necessarily as safe & predictable as certified lightplanes. Predictability is important in that flight characteristics must be predictable for a plane to respond as expected under all normal flight conditions. It is thus recommended that any design of interest be evaluated & thoroughly researched. Such research should include accident records, & the number built & flown. A few pilot interviews should include an indication of inquiring pilot experience, & suggested experience required.

The WWII fighter pilots were trained quickly, & flew planes that were much too difficult to fly for such low time pilots. Many crashed, or washed out during training. These brave, mostly young men, were at least flying planes that hundreds of inexperienced pilots had flown before them. Some later said they felt bullet proof so had no fear. Others said they were scared to death. All did their job very well, & they, like their sailor cohorts & ground pounders, & the allies, absolutely saved the world from the **evil Socialist Democrat** who swore he would "control" the world.

Any homebuilt that fully qualifies as a LSA may be flown as a LSA, even though designed before that category was approved. A private pilot can always fly a homebuilt plane without restrictions.

Many single place designs are also available from plans or kits; undoubtedly in the interest of saving money to build, store, & operate. Single place reduces payload (people) to half & the entire plane will be lighter. An example is the beautiful little Kolb Aircraft homebuilt single & 2 place Firefly & Firestar. These very similar designs have different engine hp & gross weights; 500 vs. 760 lb. The same stall speed calls for 22 vs. 27.8' wing span. Easier to stow, cheaper to build, lower cost engine, etc. It seems like a waste, but some pilot's wives refuse to fly with them, so there is merit in the single place plane. The author's pilot-wife flew, but still tried to avoid Calif. & North-East coast weather until she discovered the joy & versatility of instrument flying.

C.h.a.c A Truly Modern Plane That Anyone Can Fly Easily

In 2008 NASA announced that "in the not-too-distant future, there could be a virtual 'highway in the sky', as the average person could take to the sky in small, safe affordable, easy-to-fly personal aircraft, while traveling 4 times the speed of today's cars." They envision a glass cockpit & fully automated flight down an airway with automated clearance from other aircraft & automated flight; presumably under the control of the ATC (Air Traffic Control) system. This may sound farfetched, but not much more than 100 years ago, so was flight by man. NASA is working with the GAMA (General Aviation Manufacturers Assn) to establish affordable, safe, practical systems. Both the industry represented by the General Aviation Manufacturers Assn & NASA have, of course, made many great advances over the years. Few have been as earth shaking, of course, as the brilliant, innovative & imaginative Wright brothers. Theirs was certainly still the greatest achievement in aviation history.

NASA's current goal is to revitalize General Aviation in the U.S. They did not mention that the FAA (also a Government agency) seriously restricts any improvements of certified aircraft. Without these restrictions Genav manufacturers would have taken advantage of hundreds of advances in technology to make major improvements in their products. These restrictions are largely responsible for the failure of Gen-Av to advance as quickly & as far as the homebuilt movement has. The industry would have implemented hundreds of advances rather than a very few had these restrictions not existed. These restrictions prevented the responsible, successful, safety conscious, well established general aviation industry, from keeping up with the homebuilt movement.

These new innovations by the homebuilt movement produced exceptional aircraft that began outnumbering factory built aircraft production rates in the late 1980s. The word "homebuilt" conjures up visions of amateur designers & builders cranking out unsafe, poor performance planes that appear to have been assembled from scrap yard parts. That is far from the truth. The Experimental Aircraft Assn, based in Oshkosh Wisconsin, fostered the homebuilt movement, starting in the mid 1950's. The EAA actually was instrumental in changing several important FAA rules, & most recently, along with the AOPA (Aircraft Owners & Pilot's Assn), the development & implementation of the new "Sport Aircraft & Sport Pilot" (LSA) Category. The new LSA Category permits a small plane with "limited power & performance" to be flown under "specific conditions" by pilots with less rigorous training (though still certainly safe). Incidentally, the EAA sponsors 2 large annual fly-ins & numerous smaller ones. The largest, AirVenture Oshkosh, typically has many thousands of ultralight, homebuilt, factory built, military, & antique planes from all over the U.S.; & many foreign countries. The author & his wife flew to many EAA fly-ins over the years. On 1 occasion they saw 2 Boeing 747s that had been loaded with many homebuilt & antique aircraft, & pilots from Australia. Critical features of numerous EAA member designs have been implemented by manufacturers of all sizes & types of planes by the aviation industry. On another they saw the Concord fly, & the famous Rutan "Voyager" "round the world" homebuilt on the ground after it had flown in.

Spin-offs of the EAA homebuilt movement, as a whole, have actually, in the opinion of many, including the author, exceeded the accomplishments by the established airplane manufacturing industry & even by NASA, on many occasions. No professionally designed & manufactured aircraft has ever approached that of Burt Rutan's "Voyager". It actually flew around the world nonstop without refueling. NASA has actually bought some of his designs, & has asked him to design special purpose planes for them. Dr. Witold A. Kasper developed winglets & various other devices that were largely based on his "vortex generator technology". Some were retrofitted to airliners for major performance & definitely improvements. It is unlikely that the reader has ever flown on a modern jet airliner that did not employ some of Dr Kasper's developments. His innovative "vortex generator technology" produced the safest & most revolutionary flying wing in history; the only truly safe flying wing that may be flown manually (without computer controls). The Stealth bomber flying wing is absolutely impossible to control if the flight computer system fails. The Kasper wing could also be "tumbled" at will, & instantly stopped. Dr Kasper's innovations were adapted for use on many lightplanes, airliners, & military fighters.

EAA members perfected Composite construction methods at least a decade before the commercial or lightplane aviation industry adapted it. GE recognized that when they sent the author to AirVenture Oshkosh for a full week just to attend seminars on composite construction methods. The big Oshkosh EAA fly-in has nearly 1 million visitors during the 9 day Fly-in; & less trash on the entire 1,000 acre Whitman field property than from a 1 square foot area of ground at a typical Rock Concert. Whitman Field is virtually covered with planes of all types during the show. Steve Whitman, who operated on a "shoe string" designed & built racing aircraft & won many races in the 1930s against aviation greats like Jimmy Doolittle, who were well funded & skillfully flown. He was still performing aerobatics in his 90's. A bit of humor re Jimmy Doolittle. A published story was of an obviously very old man closing the door of his Learjet after landing. The line boy asked if he wasn't going to let the pilot out. Jimmy Doolittle, who was the very old man said, "I am the pilot". When Barry Goldwater continued flying his sophisticated multi engine plane the FAA told him he could no longer fly without a co-pilot. So he found a lady-pilot who was older than he, to serve as his co-pilot.

The EAA spawned airplane designs that often exhibit higher quality finish, & are more attractive & better performers than those built by the superb established American aviation industry. Many are professionally designed with quality of workmanship that far exceeds those of factory built planes. Many outperform factory built planes so greatly that they contributed to the downfall of the excellent, original Gen-Av aircraft manufacturers. Again, the excessive restrictions by the FAA prevented these established Gen-Av manufacturers from making cost-effective performance & safety related design improvements, when technological advances were demanded of them. The cost to make major modification approaches that of a fully certified design, so are prohibitive in many cases.

C.h.a.d Types of landing gear discussed

C.h.a.d.a Taildraggers vs. Trigear:

Most pilots prefer trigear; nose wheel vs. tailwheel. Note that the "conventional" gear has actually not been "conventional" since the 1950s, when trigear made a firm entry. Nonetheless the term "conventional" persisted. A more common term is "Taildragger". Many claim that taildraggers handle poorly in strong winds, but were better for rough terrain. The fact is that a taildragger is more "comfortable" & controllable during landing in a very strong crosswind. The author, having no alternative, once successfully landed a Cessna 140A taildragger with a direct crosswind that was in excess of 50 mph; per the "calibrated" wind sock. Above the 46 mph stall speed; he still has no idea how. Note that the airlines typically limit their crosswind component to much less than 50 mph, even though they stall over 150 mph. Conversely, it is more difficult to taxi taildraggers in a strong crosswind, since the vertical tail "weathervanes" (tends to steer the plane into the wind) & overpowers the relatively weak tailwheel steering springs. Another design that is less popular in factory built planes than in homebuilts, is the "free castering nose gear".

The superb Lake amphibian seems almost flawless in the air, on the water, & on the ground, unless there is a crosswind on the taxiway. When a moderate crosswind exists, the plane weathervanes. Weathervaning demands a periodic touch of 1 rudder pedal toe brake each time the plane approaches the edge of the taxiway; to overcorrect & head toward the opposite side of the taxiway. The plane taxis in a scallop pattern; indicating the poorest of all designs in a crosswind. People probably wonder whether the pilot has been drinking. Steering is even less effective than a weak tailwheel spring. See "Safety" above in Appendix B.

C.h.a.d.b Amphibians & Seaplanes:

Amphibians are less efficient aerodynamically; simply more drag. The very old Seabee was said to T.O. at 60, climb at 60, cruise at 60 & land at 60. Possibly a bit of an exaggeration, but it was inefficient. Seaplanes are the same without the weight & drag of a landing gear & retraction system. The main gear of the Seabee weighed 200 lb & was fully exposed, causing drag. It was easily removable to reduce weight & drag when operating only off of water. Conversely, it increased payload by 200 lb.
Many years later the Lake amphibian was introduced; fantastic on water, ground, & in the air. The main gear is exceptionally widely spaced, so they have greater than usual braking steering power. The author is not the only one who found that the brake steering is ineffective on the water; just a reflex action. Approaching a tight bend while cruising down a narrow river on the step at half power it did not turn quickly enough, until a blast of power kicked the tail around. The Lake is unique in that full rudder applied at near lift-off speed is thrilling, but uneventful. Some seaplanes dig a wing in with such action; with catastrophic results. The seaplane is very easy to land, except that judging height above very smooth water can be deceiving. Even the slightest chop can sometimes provide a severe jolt upon touchdown.

C.h.a.d.c Sailplane - Glider:

Glider is printed on the pilot's license, but a glider typically just descends until out of altitude, like the WWII troop & cargo high wing conventional landing gear gliders. The author has spoken with WWII glider pilots, & his mother's cousin towed them during WWII; he returned without injuries with his C-47 full of holes, until nearing his last mission. Unfortunately, he did not survive that mission.

Sailplanes mean different things to different people. To some they are just plain fun; a great pleasure. The author & his wife each heard external noises while soaring; she heard a train whistle. That overcame the feeling that wind noise was high; the fact that the human ear is logarithmic explains the perception error. To some they are a means of improving flying skills. To many the challenge is the key. Like sailing, it offers another competitive challenge. As such, there are classes of designs.

Spoilers are the norm for sailplanes to facilitate precise control of touchdown point. They are operated much like an engine in reverse, except for obvious limitations. They are applied when "abeam" of the desired touchdown point on the downwind leg to increase sink rate; with a similar effect as throttling an engine beak to idle. As the approach continues, if it appears that he may be "short", the pilot simply releases the spoilers momentarily for "the effect" of adding power.

Sailplanes are lifted by thermals that permit them to stay aloft. Thermals can result from any heated area on the ground, or any wind being pushed upward by passing up a hill or mountain (called slope soaring).

Sailplanes vary in L/D (lift to drag; glide ratio), meaning that it will glide 20 ft forward for every foot of altitude loss. A very poor performance sailplane has a L/D of 20:1, The old but still popular beautiful little single place Schweizer 1-26 has a wing span of 40', a glide ratio of 23:1. The gorgeous but still old all metal Schweizer 1-35 has an L/D of 39.5:1. Some newer composite sailplanes push the limit on wing span & streamlining & top 45:1. A few open (unlimited) class sailplanes approach 90 ft wing span & 60:1 L/D. Even in flat farming country, or around large cities there are adequate thermals to support a sailplane. Plowed fields heat air to cause rising currents (thermals), while cooling air descends onto nearby forest, green farm products or water allow downdrafts to facilitate a vertical circulation of air. Clouds usually generate vertical currents. Hot sand heats air over a beach vs. cooler water provide a continuous lift over the sands, & circulation on a sunny day, so sailplanes can cruise for many miles along a beach without taking time to circle in thermals. If lift exceeds sink rate the 1-35 sailplane can cruise at 67 or even 100 mph, per the below, for several hours, & return before the lift weakens. A continuous breeze approaching a mountain provides a constant "slope thermal" & lift. L/D varies with speed.

A Schweizer 1-35 has a L/D of:
39.5 at 67 mph & at 4 ft / second sink rate,
36:1 at 82 mph & at 5.5 ft / sec. sink rate,
30:1 at 100 mph & at 8 ft / sec. sink rate.

The 1-26 L/D peaks at:
23:1 L/D at 54 mph,
15:1 L/D at 91 mph.

If a 1-35 releases from an aerial tow at 3,000' in a neutral lift area, & stabilizes at the min sink rate speed of 62 mph, it is easy to compute the time to "sink" to ground level, & the distance it would travel. L/D varies with speed.

3,000 / 2.3 x 60 = 21.7 minutes total time from release to touchdown. [3,000' at 2.3 fps sink rate, & 60 seconds per minute].

21.7 x 62 / 60 = 22.4 miles total distance from release to touchdown. Considerably further than the typical lightplane mentioned above. [21.7 minutes, 62 mph, 60 minutes per hour].

2.3 fps x 60 = 138 fpm to state ROS in terms used by powered aircraft.

This is faster than the desired rate for touchdown, but the normal landing approach ends with a "flare" immediately before touchdown. "Flare" is the term used to describe a pitch-up just before touchdown; purpose is to slow both sink rate & forward speed. Flare is normally quite brief. Even airliners seem to take quite a bit of time as they flare, though some actually do not "kill" ROS totally. The author was once "threatened" by a powered plane, while nearing the end of his downwind leg in an old sailplane. There seemed to be competition for touchdown point / time. With no possibility of a go-around, he dropped the nose & held the red line IAS. He turned from downwind to the base leg prematurely; very soon after passing the point that was abeam the end of the runway, & activated the "spoilers" to increase drag. This assured his position in the traffic pattern ahead of the powered plane. He passed the downwind end of the runway 20 ft off the ground, & released the spoilers. The low drag sailplane hardly slowed. As it did he dropped to 10' AGL to benefit from "Ground Effect" (see Note 1), which further increases efficiency. If within 1 / 2 span AGL (above ground level) the wing receives benefit of the ground reducing downwash, so in effect, that gives the wing an updraft; somewhat like the wave action "uplift" that migrating birds receive from the bird ahead of them. As speed bled off, he dropped to 1 ft off the ground (to further improve "ground effect"). Instead of stopping 200 ft from the end of the runway, he glided nearly 5,000' along the runway before touchdown. Powered planes landing dead stick do not have the luxury of spoilers, but flaps (or slips in planes not equipped with flaps) offer a limited benefit of this type.

5,280 x 62 / 60^2 = 90.9 fps horizontal distance travel rate at min ROS. [5280'/mile, 62 mph glide speed, 60^2 seconds per hour.]

21.7 x 62 / 60 = 22.4 miles from release to touchdown without vertical influences.

To fly cross country a sailplane pilot must drop the nose to accelerate to a higher speed to minimize time in the "down" air; possibly 120 mph between thermals to minimize time in a downdraft or zero lift. If the pilot spends half of his time circling in thermals & half "scooting" between them, he may average 60 mph for 6 or even 10 hours. That may give him a flight of 600 miles in 1 day. Expediting time in downdrafts is also beneficial in lightplanes.
Sensing lift is mysteriously inherent in the beautiful pelicans that the author frequently watches in front of his home, but what about sailplane pilots? Sailplanes are equipped with a "Variometer" that senses ROC or ROS (rate of climb or sink) . Modern Variometers are electronic; & "dynamic", to compensate for "stick thermals". A "stick thermal" is artificial in that a jerk on the stick causes an increase in altitude or converts kinetic energy is potential energy. It trades airspeed for altitude. The transfer from air speed to altitude it appears to be a thermal, but is not. An electronic Variometer indicates ROC based on actual rather than stick thermals.

Thermals can be sensed by "seat of the pants", but this method of sensing lift is very poor, & only works with relatively powerful thermals. There is obviously no calibration. It is desirable to be able to detect any lift at all, but also the difference between the lift as the pilot circles a thermal, so that he can center on each thermal, to optimize overall lift. A variometer was the answer. If thermals are randomly located & sparsely spaced the pilot can observe his variometer & shift the center of his spiral until the lift is uniform around the periphery & then experiment to find how tightly he must spiral to obtain sufficient lift, or how large a circle he can fly & still find adequate lift. He can quickly evaluate any thermal he finds to determine whether it is to his advantage to look for another or continue in the new weak thermal. The variometer started out as a thermos bottle with a pair of rotameters. Incoming air passes through 1 "rotometer", & out-rushing air passes thru another. It indicates the rate of sink or climb.

See Note 1 below. As the sailplane climbs or descends air travels in or out of the thermos through 1 of the rotameters, which are calibrated in fpm climb or descent rate. They worked fine, except they were uncompensated; so they also read "stick thermals". A stick thermal is a slang expression for trading potential energy for kinetic energy for altitude. If the pilot pulls back or pushes forward on the stick the altitude will change. That would be an energy trade; not a genuine thermal (or down flow). A steady hand on the stick would solve this, except that turning to stay in a thermal is essential, which requires back pressure on the stick. It is not inherently obvious how to maintain a neutral lift condition; to avoid stick thermals, & sensing a thermal quantitatively is important as a new thermal is entered. So an engineer's dream; an electronic Total Energy Compensated variometer was developed to segregate stick thermals from authentic thermals. The total compensated variometer permits precise adjustment of thermals, & in the event of down drafts, optimizing speed to balance loss of altitude from diving vs. sinking air.

Note 1: Rotameters are calibrated transparent tubes that are slightly tapered inside. The floating slug either seals or lifts as air pressure changes to cause air to flow. The red slug rising indicated a down draft or down flowing air. The green slug lifting indicated a thermal was lifting the sailplane. The same instrument is used for Oxygen flow. The author had rotameters on the instrument panel to indicate oxygen flow. Small needle valves permitted individual adjustment of oxygen flow until each rotameter indicates the desired flow; based on known oxygen flow requirements for the specific altitude. Some are calibrated in altitude to eliminate the middle step. The author's wife is only 1 of 2 people he has known who can sense low oxygen partial pressure by feeling they had too little air to breathe. With the advent of high altitude airplanes along with knowledge of the need for oxygen, air crews flying above 10,000' are required to receive physiological training. This includes being placed in a pressure (actually a vacuum) chamber; opposite of a dive chamber, which the author entered for an introduction to advanced SCUBA. The intent is to teach high altitude flyers how to identify hypoxia (low oxygen level). Some feel tingles in fingers, or a variety of other symptoms. Some, unfortunately, feel nothing; including the author. Each time he performed specified tasks at the equivalent of 25,000', he had difficulty after just a few minutes, but said to himself the equivalent of "what the heck, it doesn't matter anyway". Bad; he would have simply passed out or died without reaching for his oxygen mask, or instituting a rapid descent.

The norm for sailplanes is a single wheel near the CG, & thus under the pilot. A tiny tailwheel, & wing tip skids or rollers are necessary for lateral stability. A long 3 or 4" wide skid is under the forward 4 ft or so of the fuselage to facilitate braking by use of forward stick & to save brake wear. Motor gliders & the very similar to powered gliders have landing gear that are more typical of powered planes.

Most high performance sailplanes even have a single retractable main landing gear to improve streamlining. Sailplanes have always been streamlined, & further improvement increases L/D as technology permits. Speaking as one who especially enjoys the challenge of landing, the author considers the sailplane the easiest of all types to land; only 1 wheel. Cross controlling is not an issue in heavy crosswinds. The long span & control surfaces of sailplanes are adequate to lift the low wing in a moderate breeze before starting the TO roll.

A 15 meter class typically has a speed range between 35 & 169 mph, 15 meter (49.2') wing span, water ballast, interconnecting control surfaces & retractable landing gear to enhance performance; about 43:1 L/D. Costs used start around $8,000; usually several times that.

The 18 meter class (59') is between the 15 meter & open class. Open class has even fewer restrictions, including spans typically nearing 90'.

Some newer composite sailplanes push the limit on wing span & streamlining, & top 45:1. Open (unlimited) class sailplanes approach 90 ft wing span & 60:1 L/D. Typical selling price tops $100,000. The major advantage of composites is its total controllability of intricate shapes. Ideally airfoils should be precisely shaped & continuously changing along wing span. Wing chord changes along the span, so thickness must change too. This is not practical with metal, & difficult with wood.

Newer racing sailplanes typically average 50 to 90 mph for a distance between release from tow rope to landing point. Considerable time is wasted finding thermals & climbing in them, even though the goal is to maximize average speed, with top cruising speed often over 120 mph.

It may seem unbelievable, but the 2 place sailplane altitude was set about 60 years ago in very low performance (by 2009 standards) sailplane; WWII vintage. That record stood at 44,255' for over 40 years; all without an engine past launch. It was set on the Sierra Wave, a powerful mountain wave similar to the multiple repeating water wave over a rock in a fast moving stream. The single place record was much lower for 40 or 50 years. That sailplane pilot was Larry Edgar; chairman of the White Sands Soaring Assn at Alamogordo, NM. He trained the author & his wife to fly sailplanes.

Note that aux powered sailplanes are similar to, but legally different than Motorgliders. There are quite a few aux powered sailplanes (some have monogear plus tiny tailwheel & wing tip skids or rollers) on the market. Most qualify as LSA.

C.h.a.d.d Ultralights or Ground Effect vehicle; Not Actually an Airplane:

There are too many ultralight designs to list, & they are beyond the scope of this Aero Navigation system, since ultralights are not suited for XC flying; nor are they legally an airplane. Kitplanes, Sport Aviation, Trade-A-Plane & Barnstormers do cover Ultralights. All are excellent for locating ultralights as well as all types of full fledged planes. Most pilots consider ultralights questionable for safe flight. They should be evaluated with extreme & thorough care before buying. There is another important factor that should be considered: an ultralight is much like certified planes in that it requires a trained pilot to fly one safely. Not too different than early aviation. Claude Cessna crashed on his first 13 flights in 1911, but soon after designed a successful plane. Louis Bleroit who was the first to fly across the English Channel, had not landed without damaging his plane until after the record breaking flight. He even crashed on that flight; July 25, 1909. His was one of the first few monoplanes. He averaged 40 mph on that 37 minute channel crossing, with a 25 hp engine. Training was not available to either Claude or Louis. In both cases the lack of training was very likely a big factor in the crashes.

Most pilots do not recommend an ultralight, although it does appeal to some. They are available as plans, kits, new or used. Builders should avoid even innocent looking changes. They may be hazardous. Investigate any design for safety issues & records.

FAA Part 103 defines an ultralight by limitations that include:
Single seat, 254 lb. max empty if powered (155# unpowered), 5 gal fuel capacity, 63 mph max level speed full power flight, 26.6 mph max power-off stall speed. A pilot's license is not required, but it would be hazardous & foolhardy to fly an ultralight without at least soloing a lightplane.

A vaguely similar option is a ground effect vehicle. Some are limited by design to a few feet or inches; & float on a cushion of air. A few actually fly, but are power limited to within 1/2 to 1 wingspan altitude. Ground effect begins to improve any airfoil-wing flight efficiency at 1 span height; with max efficiency at 1/2 span. Thus a very low powered ultralight can be, in effect, a ground effect vehicle; not quite an airplane. A license is not required, nor are there any weight or performance limitations. A large pasture will suffice, but a lake or bay is also excellent. Ground effect does optimize flight efficiency of a legitimate plane at an altitude of 1/2 wing span. It begins improving efficiency at 1 span height.

A toy that some have experimented with was similar to an underpowered ultralight. Given a large pasture it could take off, but did not have enough power to fly above ground effect. It could be flown all around the pasture only a yard or so off the ground.

Full sized aircraft are also subject to ground effect. A powerful example was described as 1 of many stories published after WWII. It told of a fighter pilot who had transitioned into B-24 bombers in the field without proper training. He did not learn what others were taught; the B24 would not fly on 2 engines on the same side. When he lost 3 engines, & could not hold altitude, the B-24 slowly dropped so close to the water of the English Channel that the prop often clipped water. So low that Ground Effect was optimized, so it added just enough lift to keep it airborne. As he approached the coast he pulled up to clear the gently rising terrain. As he skimmed over the end of the runway he chopped power. The overheated, overworked engine stopped instantly; locked up.

C.i Options for flying after obtaining a Private Pilot's license include:

C.i.a Aircraft availability is the same as for flight training.

First a new pilot must recognize his own capability & limitations, & never exceed them. He should establish realistic goals; what does he really want to do; & accomplish. It is usually best not to invest in a plane or an expensive club (some are) until he has a good understanding of the type & frequency of flying he will be doing. At first, even a few weeks without flying will reduce proficiency for many pilots, so do not slack off to save rental costs. Safety & proficiency are thus very good reasons to select a method that least adds to expenses each time he flies. Most clubs require cash for each flight, including fixed cost allowance. Partnerships may; or they may simply divvy up the cash for all maintenance work when the bill arrives. Sole ownership nearly gives the feeling that the only cost of flying an hour is the cost of fuel; almost encourages frequent flying. Regardless of how many hours a pilot logs he should fly often enough to maintain proficiency. Obviously fixed costs like annuals, insurance & storage are constant (nearly always) regardless of the number of hours flown. If fixed costs add up to $2,000 per year, that's $200 per hour if only flown 10 hours per year; plus fuel. If 100 hours per year, $0 per hour seems too good to be true.

Realistic goals should be set & kept. A new pilot is rarely well equipped for a high performance plane. The slowest lightplane or Sportplane is considerably faster than a 200 mph Vette (Corvette) on nearly any trip because of speed limits, stop lights, etc. With only 300 hours in his log book, the author set a long term goal to fly his very young family across the Atlantic in a 200+ mph D-18 Beech twin; some day in the distant future. After 6 or 7 hours of dual in that beauty he realized that his goal was not realistic. The cost of fuel consumed on such a long flight, with 2 engines rated at 450 hp each, would have been enormous. More importantly that large fuel load seriously limited the payload for a family of 6. With a 1,200 mile range, the D-18 could fly across the Atlantic, with mid ocean landing sites, but not necessarily safely considering the frequency of severe weather forcing a return to the departure point. The North Atlantic weather leaves much to be desired, even in the summer. With flying experience previously limited to 65 & 85 hp engines, 900 hp was also an excessive leap. Hundreds of pilots have flown a wide variety of types of SE & light twin lightplanes across the Atlantic. Max Conrad was certainly not the only one to fly lightplanes around the world. **Dick Rutan was, & still is the only one to fly around the world nonstop; without refueling. His plane, which was specially designed for that flight by his brother Bert Rutan, was far from a lightplane, of course. It was, however, built under the EAA guidelines. More details elsewhere**.

Realistic goals for a new private pilot might include renting, joining a flying club (which has 1 or more planes & several member pilots; & usually also CFIs to train student pilots), forming a partnership, or buying a plane outright. Most popular are the exceptionally safe, bullet proof (exceptionally reliable) Cessnas; a 100 hp Cessna 150, 145 or 160 hp Cessna 172, 210 hp Cessna 182, or a 300 hp Cessna 210 RG. All except the 150, & the later 152 are available with RG, & even turbocharged. The 210 is the only one not offered with F.G.

C.i.b. Suggestions to any new pilot:

Just enjoying the new flying privilege in whatever plane is affordable, as long as it does not require greater skill than he has.

Most important: obey the regulations. Their primary goal is safety.

Never try anything that you did not first try with a CFI aboard; such as low level flying; hedge hopping, or even very minor aerobatics.

Enjoy demonstrating new Aero Navigation skills for 30 mile; or 1,000 mile cross country flights. Fly in a random direction for an hour or several, with plenty of fuel. Then try to determine location with only the Sectional. Such a test is easy with a GPS for back-up, but with only an OMNI, a frequency cannot be randomly selected if he finds himself lost. Must have a good idea where he is. A great confidence builder, & good way to enjoy the beauty of the local countryside. It's hard to find a place in the U.S. that is not truly captivating, although the desert & mountainous Southwest or coastlines are hard to beat.

Enjoy practicing stalls, turns around a point, & possibly spins. Shoot landings till tired or low on fuel; the author often did; especially when a low time pilot He has also always shot several landings &/or instrument approaches per week for pleasure, self satisfaction, & proficiency building. He can see how closely he can come to a specific spot on the runway without adding power or "killing" altitude; just pure good judgment. Switch runways for a stiff crosswind just for practice. Not a good idea to find out on a long XC that there is only 1 runway & the cross wind is too stiff for current skill level.

Work on an advanced rating, such as a CFI, an instrument or glider rating, or begin aerobatic training. Any type of training will improve flying skills & knowledge.

Begin training in higher performance planes, but only when confident of adequate skill & knowledge before considering an XC.

APPENDIX D: Overflow or General Extraneous Info: Aerial Navigation Systems, Avionics, Instruments, & Tools.

D.a Tools: The tools that were discussed in paragraph 3.6.6 are the most common & important, but other tools & instruments are often required; some are optional for some planes & activities.

D.a.a. Instruments required for VFR flying:

Air speed indicator
Altimeter (single needle is rare, but allowed)
Clock
Compass

ELT - Emergency Locator Transmitter.
Engine Temp; generally oil temp
Fuel gage (1 for each fuel tank)
Navigation Com for OMNI & Communications. Not mandatory, but usually also a panel mounted "radio"
Oil Pressure
Tachometer
Transponder if plane has an electrical system.
Turn & Bank Indicator; electric powered if plane has an electrical system; vacuum powered for planes without an electrical system. Not mandatory. A Skid-Slip Indicator is included in both T&B & turn coordinator. It indicates a coordinated or uncoordinated Bank; an important simple level type instrument

D.a.b. Instruments required for IFR Flying:

IFR Instruments (in addition to VFR instruments)
Altimeter, Sensitive, (3 needle)
Attitude Gyro
Directional Gyro
T&B or Turn Coordinator
Navigation Com
ROC (Rate of Climb - Sink Indicator)
Preferable additional Avionics: Second Navigation Com, additional Aero Navigation "radios" such as ADF, LORAN, GPS, Glide slope receiver

D.a.c Important Relevant Info about Instruments.

D.a.c.a VFR Instruments

D.a.c.a.a Airspeed Indicator & Some Important Relevant Info.

The Airspeed Indicator is one of the more important Aero Navigation instruments in that speed is critical to nearly all Aerial Navigation & flying activities, as well as flight safety during approach, landing & T.O. Fig D 1 illustrates the mechanism, sensing diaphragm & pitot static system.

There are 4 types of "speed" in flying; 3 are called Airspeed. All are relevant to Aerial Navigation. Indicated Airspeed (IAS), Calibrated Airspeed (CAS), True Airspeed (TAS), & Ground Speed (GS). Airspeed may be written as 1 word or 2.

The first type of "speed", IAS is obviously directly read from the instrument.

IAS is dependent upon air density, temperature, & speed of air entering the pitot tube. The pitot air pressure is counterbalanced by a "Static" pressure sensing port. The pressurized 3" diameter diaphragm inflates sufficiently to operate the mechanism that causes the final shaft in a delicate, precision gear system, to rotate the instrument needle. The thin brass sheet diaphragm is somewhat corrugated to improve flexibility & uniformity of flexing. Two such discs are closely spaced & welded at the edges.

CAS is IAS, corrected by use of an instrument calibration.

TAS is determined, as stated previously, by use of the rotary slide rule side of the E-6B, with knowns of OAT (outside air Temperature), CAS, & Temperature. TAS is the speed through the air, regardless of heading, altitude, or wind. TAS is equal to CAS at 59°F & at sea level (29.92" Hg atmospheric pressure "Standard" atmospheric temp & pres).

A typical Airspeed Indicator & its mechanism, sensing diaphragm & probe (pitot static system) was illustrated in Fig D1. It is usually a dual scale instrument; calibrated in both mph & knots. Both are called "Indicated Air Speed" (IAS). The standard unit of measure was mph until a few years after WWII when the gradual change to knots began. Thus the dual scale has existed for several decades. The unjustified standardization to knots for wind velocity by the Feds forced public & industry acceptance by making it inconvenient to use mph. It cost industry an enormous amount of time & money. Some Airspeed Indicators have "integral correction capability", so that they read both IAS & True Air Speed (TAS).

As altitude or temperature increase the air obviously becomes less dense. TAS is usually (above 59°F at MSL; standard temperature) higher than IAS. That spread increases with altitude. True & Indicated Air Speeds are inversely related, but not inversely proportional, to altitude & temperature. The Absolute temp then has a minor impact

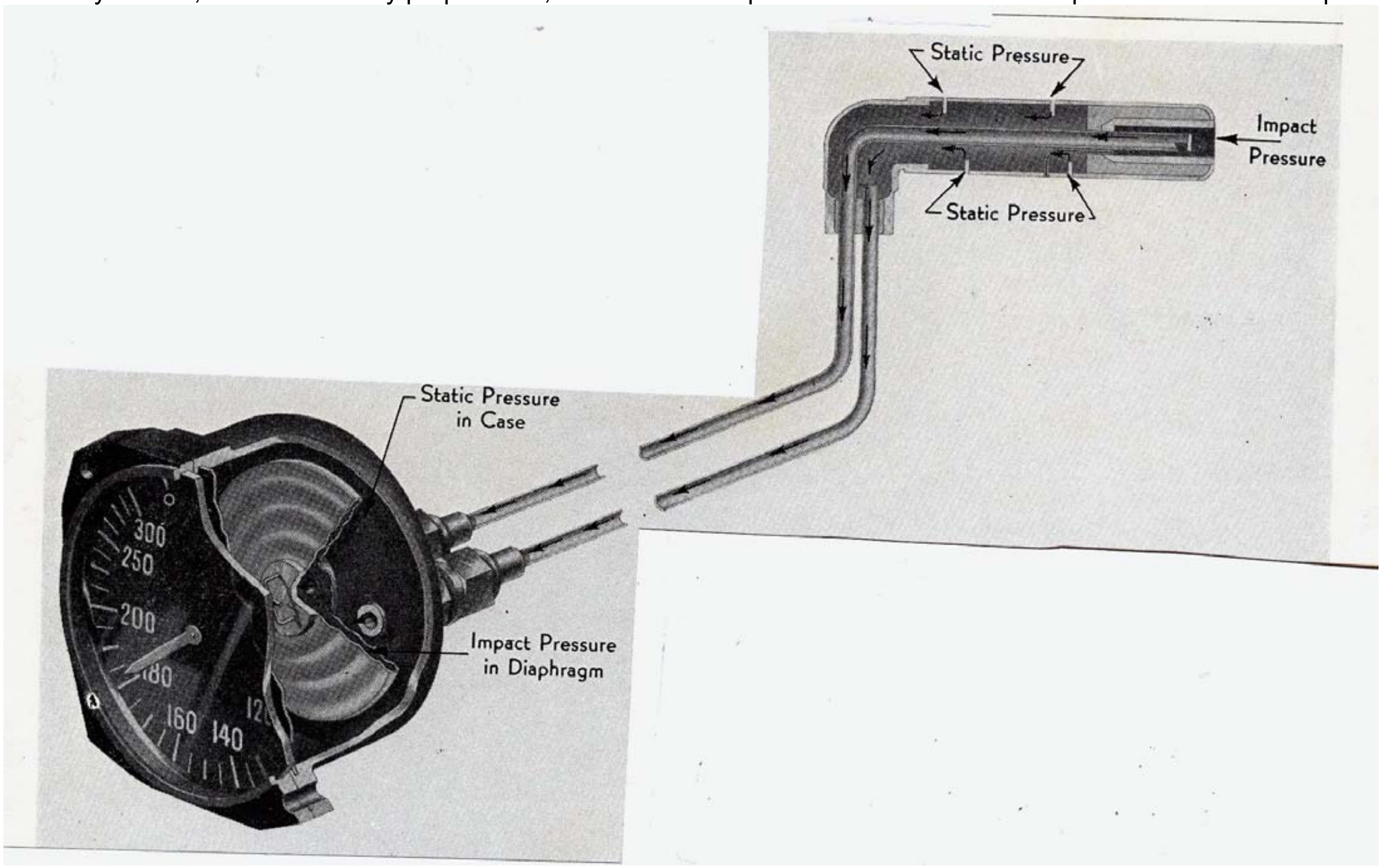

Fig D-1; The Airspeed Indicator with Pitot Tube

since the "base" is a large number (-459.69°F; ref Rankin). The ambient temperature range is typically less than 100°F. The relationship is complex, as was illustrated previously in the discussion of the E-6B "Dead Reckoning Computer".

D.a.c.a.b Altimeter:

A simple single needle is legal for VFR close to the airport. It has no means of adjustment for elevation or pressure changes. Cross country flying requires a Kohlsman window to permit adjustment as barometric pressure changes.

Most altimeters are the Sensitive type, which have 3 needles & a Kohlsman window, in which the atmospheric pressure (local atmospheric pressure, adjusted to MSL) should be set. See Fig D 2. This allows a pilot to adjust the altimeter setting as it changes, especially during a long XC flight, from 1 pressure system to another. "Pressure altitude" may be read at any time or altitude by temporarily setting the Kohlsman window value to standard pressure; 29.92.

Each of the 3 needles of a Sensitive Altimeter is a different length. Until jets flew so high that the tens needle became critical, the tens needle was the shortest. It was soon lengthened for high altitude aircraft. Most lightplanes continue to use the altimeters with the shortest needle representing tens of thousands of feet. All needle lengths read the inverse of value. The ratio is 10:1 on each adjacent needle.

On all except jet planes the longest needle moves to the no. 1 as the plane reaches 100 ft altitude. As the plane climbs, it continues turning in a clockwise direction until it returns to the zero. By that time the mid length needle has moved to the no. 1 to indicate an altitude of 1000 ft. As the mid length needle returns to the zero, the shortest needle moves to the no. 1 to indicate an altitude of 10,000 ft. An airline captain once misread the short needle & made an approach to a non-existent field elevation of 10,000 over Hawaii. Had he misread it the opposite direction they might possibly have ditched at cruise descent speed into the Pacific.

Lightplanes seldom see the shortest needle much beyond the 10,000' point, but a pilot must be alert to all 3 needles.

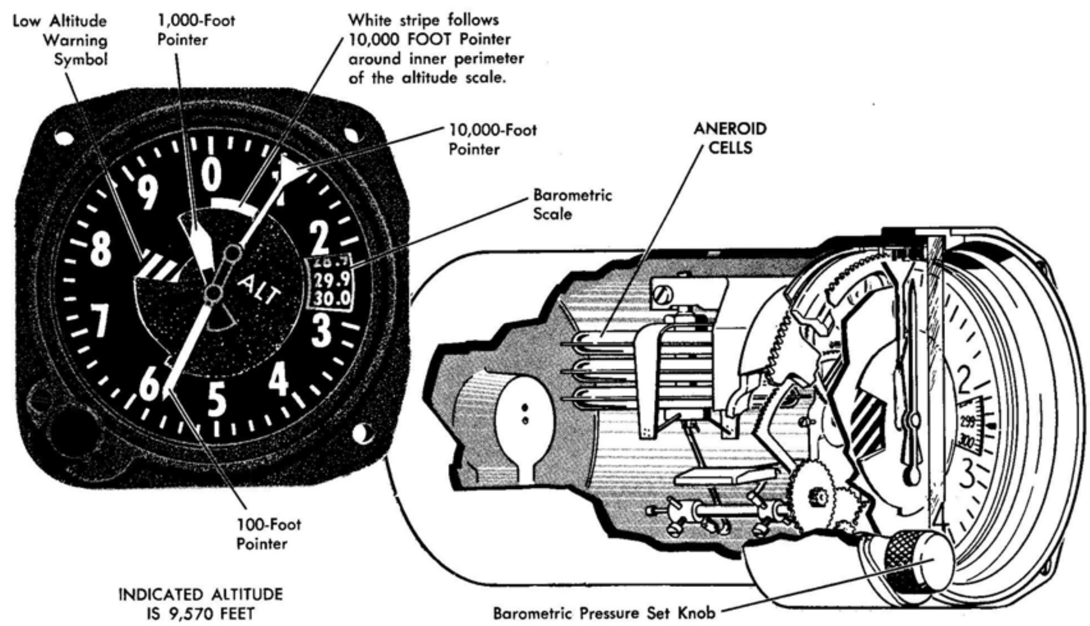

Fig D2: Altimeter with Kohlsman Window & Cut-Away

Obviously the gearing drives all progressively, so each needle progresses slowly from zero to the final altitude. When each needle is on the no. 1 the altitude is thus 11,100'. In Fig D 2 the high altitude jet type altimeter shows the longest (tens of thousands of feet) needle approaching (although it seems to be on it) the #1. Since the middle length needle is left of the zero index, it is obvious that the longest needle is actually below 10,000'. Something over 9,000'. The hundreds of feet can be estimated from the thousands needle, but the hundreds needle reads 570'. Thus the altitude is 9,570'. There are several sensing elements in an altimeter; each is much like the diaphragm in an airspeed indicator; the difference being that the altimeter diaphragm continually expands as altitude increases.

Cruising altitudes are established by regulation under nearly all conditions, so the altimeter & proper settings are important for safety. If a pilot fails to monitor & reset his altimeter as he moves into a different pressure zone he will cruise at an incorrect altitude. Although mid air collisions are virtually impossible statistically, the risk does increase when pilots fail to update their altimeter settings.

D.a.c.a.c Clock

A clock is very important for timing flight time, time of fuel burn on each fuel tank, time between fixes, & the most critical, for timing instrument approaches.. The more functions the better. Ideally local time, Zulu, stop functions for total trip flight time & approach or fix to fix time. The more functions the less chance of subtraction errors that could lead to fuel exhaustion. A multi function panel mount is much more practical than a stop watch or wrist watch with stop functions.

D.a.c.a.d The Compass was discussed in detail in paragraph 3.6.6. 4 above.

D.a.c.a.e ELT - The Emergency Locator Transmitter broadcasts a signal on the emergency frequencies if triggered by occupant or g-forces of sufficient magnitude to indicate a probable crash landing.

D.a.c.a.f Engine Temp gages; generally oil temp & often also a cylinder head temp.

Engine condition is essential. Engine Temp is an indicator of proper operation. Cylinder head temp &/or oil temp are typical gages. Most aircraft engines are air cooled, so there are no other items to sense.

D.a.c.a.g Fuel gage:

Most planes carry fuel in wing tanks; thus 2 fuel gages are generally required. Calibrated fuel gages are necessary to assure adequate fuel at any point during a flight. Another safety advantage of high wing planes is that gravity provides flow so that fuel pump is not normally required. Low wing planes have the added weight & potential for failure of redundant fuel pumps, as well as an additional complexity to monitor. Most low wing planes are fitted with an engine driven fuel pump plus an electric powered pump that should be operated during T.O. & landing for additional safety; something else to add to a check list; or to forget to operate; or turn off during cruise. A fuel pump demands another instrument with its reliability, cost, space & weight.

D.a.c.a.h Oil Pressure

Oil Pressure is vital to engine health. Most do not recommend application of take off power until the oil temp gage is “off the peg”; after oil has warmed up sufficiently in cold weather that the engine will be well lubricated.

D.a.c.a.i Tachometer

A Tachometer is necessary to establish cruise power, & to verify that adequate power is available on takeoff. If a tach with an engine fitted with a fixed pitch prop shows a lower rpm than normal for any given speed during the take off roll, the take off should be aborted if enough runway remains. Engines fitted with a fixed pitch prop will turn progressively faster as speed increases, because the load, & thus manifold pressure decreases with forward speed. Constant speed props change pitch per prop control adjustment to maintain propeller rpm, once take off power has been applied.

A revolution counter is included in most tachs; calibrated in hours of operation based on a nominal rpm.

D.a.c.a.j Transponder

A Transponder is mandatory except for planes that were certified without an electrical system, & were never modified to add one. It responds to a sweep by FAA radar, & sends a return signal with a specific 4 digit code; 1200 if VFR & not previously assigned another code by a controller.

D.a.c.a.k Turn & Bank & Turn Coordinator are similar instruments that are functionally interchangeable. See Fig D 3 for both types. It shows the differences in gyro axis arrangements.

Rarely used In bizjets because of limitations; either may be used as the only gyro instrument provided in the partial panel for limited & emergency IFR in the rare event of a failure of the vacuum powered DG & AG full panel instruments for serious IFR flight.

The Turn Coordinator was developed to replace the T&B to facilitate use with an autopilot. The T&B had been providing the same info for decades without the slanted (30° forward of the vertical) Gyro gimble-cage that separates the 2 types of primary panel instrument mechanisms. This allows the turn coordinator to respond to aircraft roll as well as yaw (turn).

The TC indication represents a resultant of the roll and the yaw rates, so it responds more quickly at the beginning and end of a turn than a turn and bank indicator. This nonlinear response results in increased difficulty in “stabilizing” either on a “standard rate turn” or on “wings level” normal flight. Pilots who are not aware of this inconsistency may misinterpret a rate of turn as a roll indication, or vice versa. The pilot tends to cause the miniature airplane to over & undershoot, so it takes a few cycles to stabilize it. That is not conducive to precision turn rate, as desired for IFR flight. The TC & T&B are intended for continuing IFR flight if the attitude indicator fails. Called 'partial panel' operations, this can be safely used to complete any IFR flight, including IFR Approach. In fact, what is now called a partial panel was in years past the only IFR gyro available. Each contains a slip-skid indicator as described below.

The T&B gyro gimble-cage rotational axis is vertical. Both types have a gyro spin axis that is parallel with the aircraft lateral (pitch) axis. For reasons of redundancy, these 2 instruments are electrically powered, since the AG & DG are

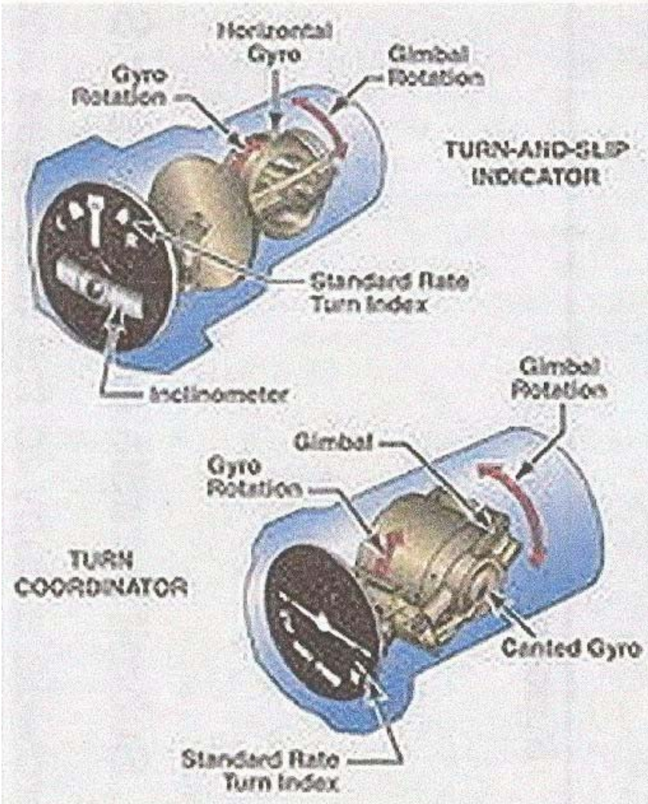

Fig D3: Turn & Bank & Less Safe, but more "Modern" Turn Coordinator

vacuum powered. The primary merit in the Turn Coordinator is to improve autopilot performance. It was installed in lightplanes only because of the "modern appearance". It is generally avoided for use in larger aircraft, including jets. Most experts & high time pilots consider the TC less safe, & thus prefer the T&B.

The Coordination portion of both the TC & T&B are essentially just a weight type level; inverted version of a bubble type level. The earlier TC "level" was mounted lower on the instrument face, so was more difficult to see. This was undesirable since the bank portion of both instruments is used constantly to verify proper "trim" in "straight & level flight", or to assure coordinated turns; neither slipping nor skidding. Later TCs used a "level" located similar to the T&B. Conversely the turn portion of either instrument is used for establishing a standard rate turn, & for timing turns; rarely a concern during VFR flight. A "TC (or T&B)" instrument is critical to Aero Navigation under IFR conditions to facilitate turning to assigned headings. This is accomplished with the TC & T&B by aligning the needle with the "Dog House" reference to accomplish a 2 minute turn. A deflection of 2 needle widths results in a 3° per second turn rate (called a 2 minute turn, since 2 minutes results in a 360° turn). That turn rate is held until within a predetermined angle of the desired heading, to allow for roll-out time.

The vertical needle of the T&B is controlled by a gyro that senses only a turn. The gyro is "caged" (restrained) against rotation about the lateral or longitudinal axes, but allows the cage to rotate about the vertical axis. Neither pitch nor roll impacts this needle directly.

If the pilot is instructed by ATC to turn from his heading of 090° to a heading of 150° he knows that the 60° standard rate turn will take 20 seconds. He must, however correct for the transition time; time to roll into & out of the turn. "If" he knows that it takes him 5 seconds to roll in & 5 seconds to roll out, he will average 1 minute turns for 10 seconds, so will require an extra 10 seconds between entry & end of roll-out. But he will begin "roll" out of the turn 25; not 30 seconds after beginning "roll" into turn. He must pay very close attention to the controller's exact wording, however. The controller may actually want him to turn to & from these headings, but instruct him to turn left rather than right. The time must then change from 20 seconds to 160 seconds. The bank angle to turn 3° / sec depends on the TAS.

The weight is a readily visible black "agate" ball in both instruments (TC & T&B) and is essentially a "level" that permits a pilot to remain in a coordinated turn (neither skid nor slip). Regardless of turn rate & bank angle, the ball will remain centered if the turn is coordinated; as it should be. The ball is dampened from excessive motion by immersion in kerosene. Fig D 3 shows the ball centered for coordinated flight, & no turn by vertical needle of the T&B or wings of the turn coordinator. A very important (especially for multi engine planes) "rule of thumb" simplifies the correction of skid or slip: “Step on the ball”. If the reason for the shift is a loss of an engine in a light twin, & the ball is to the right, step on right rudder pedal, because the power just dropped to zero, & the drag just increased on the left side. With this simple rule he need not know instantly that the left, & not the right engine has failed. It may seem obvious, but it is not intuitively obvious which engine failed. This rule is more important in multi engine aircraft, because of the critical nature of engine failure, but it also helps in a SE (single engined plane) during a climb. In a climb the plane is pitched up to increase lift, so this slows the plane. The increased wing angle of attack results in a change in longitudinal axis & thus of angle of attack of the prop. The prop blade on the left side of the longitudinal axis will suffer a reduced angle of attack, & the right side an increased angle of attack, causing the plane to yaw to the left. This was called torque until someone realized the real cause. It is now called “P factor”. The delta thrust causes a yaw to the left, which must be countered by right rudder pressure to keep the ball centered. The only way to verify proper rudder pressure is to observe the ball.

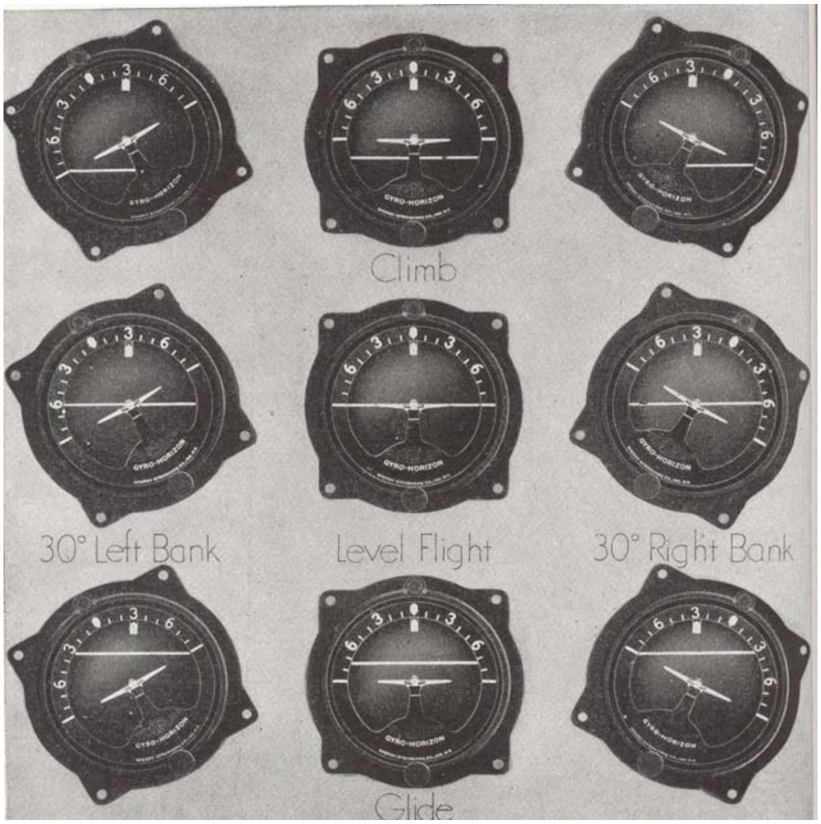

Fig D 4: 9 Typical in Flight Situations on Gyro Horizon

The “P factor” is not the only puzzling, but explainable fact in flying. Another one of those is the fact that it is not obvious to the pilot of a multi engine plane which engine failed. It may seem obvious, considering the pilot might sense a yaw, & can read engine instruments, but it is not. Stepping on the ball is a very fast way to at least start the process of correcting for an engine failure. Another puzzling case in which the T&B is informative is attitude under IFR conditions. A person has absolutely no idea which way is up if he cannot see a known outside reference; such as the horizon. The T&B with ball centered explains this. A 2 minute turn is a moderately shallow bank, except at a very high speed. If ball is centered it feels like he is flying straight & level.

D.b. IFR Instruments; (in addition to above VFR instruments)

D.b.a Attitude Gyro

The Attitude Gyro (AG is also called an Artificial Horizon) serves well as a visual horizon reference when in clouds reference under IFR conditions. See Fig D 4 for 9 typical in flight conditions.

The 9 conditions of Fig D 4 show a single line that represents the horizon. The author prefers the AG that has angular scale that follows the horizon rather than the aircraft. Most AGs now show simulated section lines along the ground & blue sky above the horizon. Reading the 9 variations from top left across:

1. 30° left bank & pitch-up.
2. Wings level, pitched up into climb.
3. 30° right bank in climb.

4. 30° left bank, level (nose on horizon).
5. Wings level; level flight.
6. 30° right bank, level flight.
7. 30° left bank, steep descending flight.
8. Wings level, nose down.
9. 30° right bank, descending.

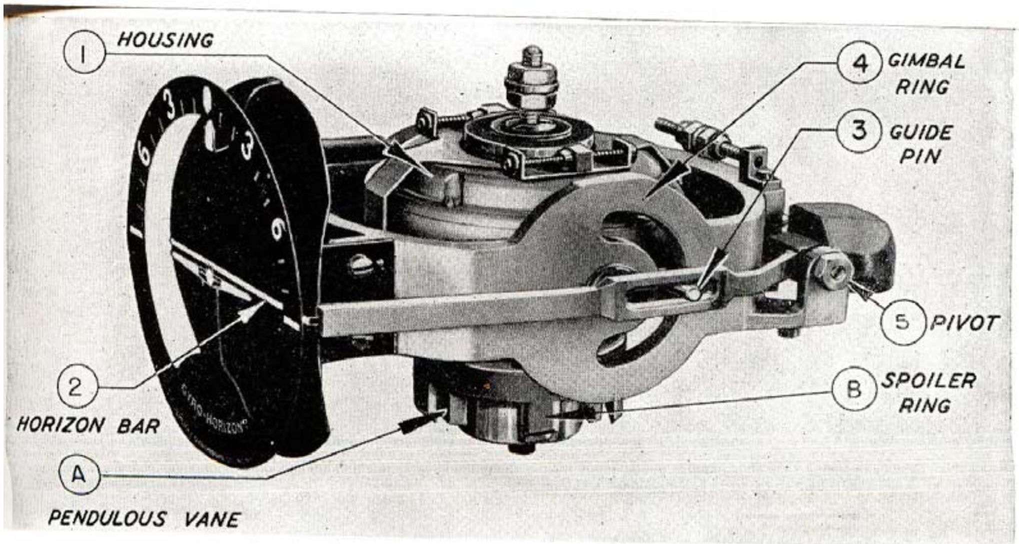

Fig D 5: Cut-away of an Attitude Gyro Instrument

See Fig D 5 for the cut-away of an Attitude Gyro instrument. Cut-away shows mechanism & gyro. Display limits the artificial horizon display to pitch & roll, & always matches the orientation of the actual horizon.

D.b.b Directional Gyro (DG)

A Directional Gyro (also called a Gyro Compass) is a free floating gyro instrument that requires resetting before takeoff, & as it precesses during flight. Most DGs are vacuum powered. See Fig D 6.

Small arrow heads are located at 45° intervals, along with a movable heading Bug (pair of indicators) to flag any desired heading. These eliminate Aero Navigator memory problems & gives an easily seen index precisely where it is

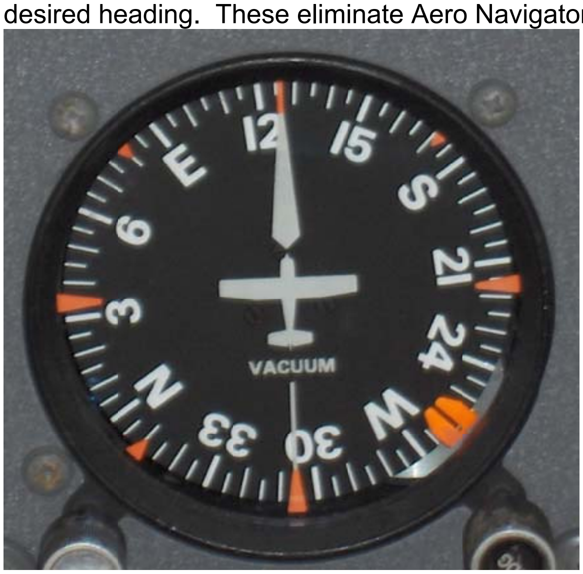

Fig D6: Vertical Card Compass; DG, Slaved Gyro, Remote Compass, or Pure Magnetic Field Powered Compass

needed. Several instruments use variations of the vertical card compass & DG. A variation of the basic DG is a vertical card slaved to an isolated flux gate magnetic sensor to gain the best of both types. The greatly improved instrument allows the flux gate compass to provide basic magnetic info while the gyro portion dampens the various magnetic compass disturbing influences such as turbulence. It also reduces the effects of EMI internal to the plane.

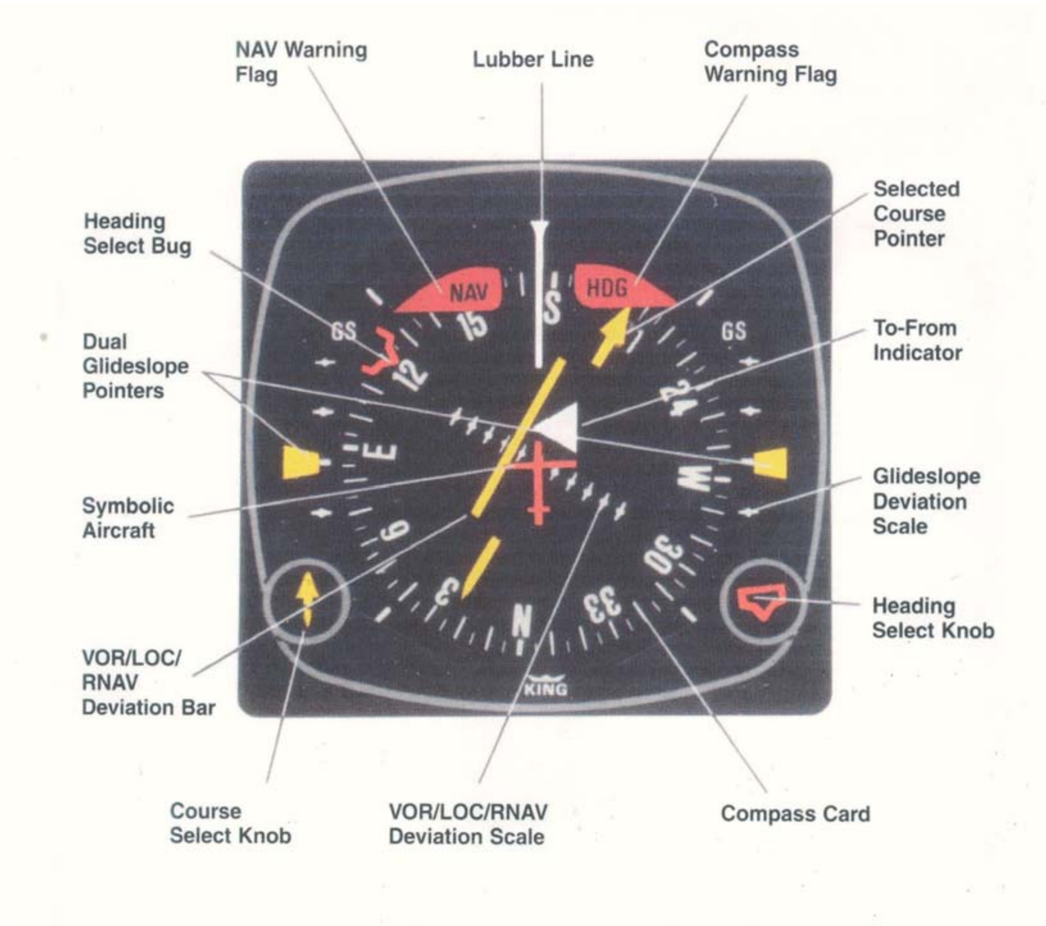

Fig D7: HSI. A Superb Advanced Instrument that Includes Several Functions. Described in great detail in later Aero Nav system in this series.

Compasses in summary: Compass type instruments include totally earth magnetic field powered, vacuum operated gyro powered. Most magnetic powered compasses have a conical frustum card that is calibrated in angular degrees. Most slaved gyro or pure gyro operated compasses utilize a vertical disc calibrated in angular degrees. Most instruments that display a compass type directions also utilize a vertical compass type card.

D.b.c HSI (Horizontal Situation Indicator)

A major improvement over the best of the compasses is a further extension of the flux gate slaved gyro; the HSI (Horizontal Situation Indicator).

It adds to the slaved gyro the OMNI & Glide Slope CDIs for an all inclusive instrument which makes an enormous difference in pilot workload; especially valuable during IFR approaches. It will be discussed in great detail under instrument approaches. See Fig D 7

The HSI is discussed in great detail during the Instrument approach Aero Navigation system.

D.b.c ROC; Also called VSI; Rate of Climb or Vertical Speed Indicator:

The ROC (Rate of climb, or VSI for vertical speed indicator) is primarily intended to allow the pilot to establish & hold a predetermined or reasonable rate of descent. See Fig D 8.

Fig D-8 - VSI; Also Called ROC

A single needle that moves up or down a full 180°, typically to a max of 2,000 fpm for reciprocated engine powered lightplanes. Descent rates greater than 2,000 fpm range do not damage the ROC. Controllers often instruct a pilot to descend at a specific rate of sink (descent). The ROC facilitates that. Timing descent by use of an altimeter is possible, but very inconvenient & it changes continuously, so requires trial & error. Holding any descent rate without the ROC would be difficult. ROC during a climb is normally determined by “excess hp”; power available less power required to cruise straight & level. Rate of climb can realistically be increased only by increasing pitch attitude at the expense of climb speed; the norm. Lower climb speed increases climb rate, but at the expense of lower GS.
The VSI also simplifies descents to provide the optimum altitude during VFR as well as IFR, like approaches to an airport.

If a plane is cruising at 10,000’, at a ground speed of 100 mph, is 50 miles from the 1,000’ elevation destination airport, needs to descend at a rate of 4000 fpm to a 1,000’ traffic pattern altitude. 50/100 = 0.5 hours = 30 minutes to airport. 8,000/30 = 267 fpm descent rate. If the answer were 1,000 fpm he may prefer to start the descent earlier for a more efficient & less damaging (by cooling cylinders) ROS (rate of sink). The ROC instrument makes any descent rate easy to hold. Some LORANs have an easily programmable feature that allows a pilot to enter cruise altitude & desired descent rate, & the LORAN flags descent time & advises of adjustments to correct descent rate during the descent.
An ROC instrument mechanism is similar to that in an altimeter, except that the diaphragm has a controlled leak.

D.c. Avionics

D.c.a Low Frequency Range Receiver

The Low Frequency range was the best available XC flying Aero Navigation system from the 1920s until OMNI Range was fully implemented. It was, being low frequency, susceptible to thunderstorms & even lesser electrical disturbances. The receivers involved predated solid state electronics, so was large, heavy, a heat generator, & susceptible to damage from its own heat. Genav LF receivers were smaller & lighter, & usually included a LF transmitter. These units are now obsolete except for long range overwater communication & in 3rd world countries. They are, however, quite low in cost, so as of 2009, the administration actually plans to obsolete other higher cost Aero Navigation systems. There is still enormous controversy over their trying to obsolete the invaluable LORANs, & allowing the GPS satellites to deteriorate beyond practical usefulness.

The Low Frequency Range & the fascinating & challenging Low Frequency Range instrument approach procedures are discussed in great detail in the appropriate subsequent Aero Navigation system discussion.

The Natural Frequency Bands

BAND	Abbreviation	Frequency range	WAVE LENGTH Longest	Shortest
Audio	AF	0.02 to 20 kHz	<:::><:::>	20,000 m
RADIO				
Very low frequency	VLF	10 to 30 kHz	30,000 m	10,000 m
Low frequency	LF	30 to 300 kHz	10,000 m	1,000 m
Medium frequency	MF	300 to 3,000 kHz	1,000 m	100 m
High frequency	HF	3,000 to 30,000 kHz	100 m	10 m
Very high frequency	VHF	30 to 3OOmHz	10m	1 m
Ultra high frequency	UHF	300 to 3,000 MHz	100 cm	10cm
Super high frequency	SHF	3,000 to 30,000 MHz	10cm	1 cm
Extremely high frequency	EHF	30,000 to 300,000 MHz	1 cm	0.1 cm
Heat and Infrared		3xl0^{11}to3.6xl0^{14} Hz	10-1 cm	8.3x lO^{-5}cm
Visible spectrum		3.6 x 1014 to 7.8 x 1014 Hz	8.3 x 10^{-5} cm	3.8x lO^{-5} cm
Ultraviolet		7.8 x 1014 to 2.4x 1016 Hz	3.8xlO^{-5} cm	1.2 x 10^{-5}cm
X-Rays		6x 10^{15} to 5x10^{19}Hz	5x 10^{-6} cm	6x 10^{-10} cm
Gamma rays		6x 10^{18} to 6x l0^{20}Hz	5x l0^{-9} cm	5x^{-11} cm
Cosmic rays		3 x l0^{20} to 10^{23} Hz (+)	10^{-10} cm	<3 x 10^{-13}

Fig D-9: Radio Frequency Band, Including Aero Nav Frequency Bands

Modern aviation uses many unique frequency bands for specific applications. Figure D-9 illustrates these, including wave length, which is critical to antennas. Nominally antenna length is 1/4 of the wave length. Some antennas contain integral electronic devices that allow reduced length. In other frequency bands different tactics are applied.

D.C.b Direction Finder Receiver; Receives Non Directional Beacon

A round loop antenna was physically rotated by hand to establish direction to-or-from the low frequency broadcast transmitter. The old loop was one of the earliest & most valuable Aero Navigation “aviation radios” when introduced.

D.c.c ADF Receiver

An ADF is an upgraded NDB receiver that used a large round antenna called a loop to establish an ambiguous direction to-or-from a radio frequency transmitter. The earlier ADF (automatic direction finder) automated the process, but still gave an ambiguous direction indication. In the late '60s the movable loop was replaced by a solid state loop that removed the “to-from” ambiguity. When it pointed to 360° it was 360°; not possibly 180° instead. An ADF is still a vital tool for many applications, including some IFR approaches. The Narco ADF 31A that the author installed as soon as the solid state loop was available offered a low frequency AM range that included the standard broadcast band. The bands were 190 to 430 KC, 420-850, & 840-1,750. It is possible to listen to Rush Limbaugh, Paul Harvey or music while flying IFR, as long as the volume was lower than the controller frequencies. It is possible to "home in on" a standard broadcast station if flying toward small town that has no nearby VOR. .

Some ADF receivers include a Marker Beacon, which is essential for some IFR approaches. The ADF-31A has a volume control that pulls out to activate the marker beacon receiver;

The ADF, including the ADF-31A & the fascinating & challenging ADF instrument approach procedures are discussed in great detail in the appropriate subsequent Aero Navigation Aero Nav system.

D.c.d OMNI Receiver with Com Transceiver

The OMNI Receiver with Com Transceiver is still the mainstay of Aero Navigation for serious XC flying, including IFR. OMNI includes glide slope capability for those willing to spend a little more for the best high precision IFR approach system ever developed for normal applications.

A communication transceiver is required for most operations & airspace. A VHF Navigation Com is generally necessary. A Second Navigation Com is preferred, even if only for standby-emergency use.

Early testing & limited use of OMNI began in 1944; & expanded in 1947. By 1952 the U.S. had a full complement of OMNI Range airways. These early receivers were primitive; as was the associated transceiver. The initial transmitter was crystal tuned, but limited to just a few frequencies, typically 4 to 7. The single receiver in the same frame was analog tunable as the typical AM standard broadcast radio. The VOR frequency could be tuned by listening for the Morse code identifier emitted, still to this day, by the VOR OMNI Range station. The transmitter frequency could be tuned by whistle stop tuning. Inconvenient, but better than for the OMNI signal. Needless to say the VOR signal was lost during the communication process. This was certainly not ideal during IFR. Both VOR & Com are always critical during IFR, & important much of the time. At that time the Navigation com was several times as large, so dual Navigation com was rare. It's no wonder that the AOPA cautioned pilots not to fly IFR; too complex & inconvenient.

Soon the electronic manufacturers such as Collins, Narco, & ARC offered digitally tuned 90 channel transceivers, & then 100, & 360 & later 720 frequency channels. All provided a continuous navigation frequency that was independent of the transceiver frequency. A major advance; simultaneous com & navigation.

The VOR-OMNI range systems, including the fascinating & challenging VOR instrument approach procedures are discussed in great detail in the appropriate subsequent Aero Navigation course.

D.c.e Marker Beacon

Some instrument approaches require a marker beacon for identification of very small (thus precise) critical locations along the approach path. Marker beacons can be a small special purpose receiver, or integral with other avionics units.

D.c.f DME

The DME is integral with some OMNI receivers, & provides additional distance information. The distance, however, is not direct reading. It must be interpreted based on altitude, as explained in the VOR-DME Aero Navigation system in this series. It was considered an excellent capability until LORAN & GPS were introduced with more user friendly capabilities.

D.c.g DCE

DCE (Distance Computing Equipment) is still being sold, but is not as useful as before LORAN & GPS. It offers similar information as the LORAN & GPS, information that was unavailable before the DCE, LORAN, & GPS. It requires dual panel mounted OMNI, & a programming effort that is less than ideal. Further, it could only provide info on VORs that were programmed for a given route. It is actually quite a complex computer that integrates info from 2 VORs & establishes a ground track. It affords a track that is “off-airways”, which is quite an advantage, but so do LORAN & GPS. The DCE was the first Aero Navigation system to offer continuous direct instantaneous "fix". The author installed one when it became available in 1982. Soon after, however, the LORAN C entered the market, which provided the same information with less programming effort. Still quite useful. Discussed in detail in Aero Nav system No. 20.

D.c.h LORAN

The original LORAN was quite primitive and had low accuracy. That used during WWII & for a decade after was quite ingenious, complex, & very much an engineer’s system. It required special charts & unique plotting methods. The LORAN receivers were upgraded over time, but were always very large, heavy & inconvenient to prepare for use & to use.

LORAN C was available to the military in the mid 1950s. It was not until the 1980s that LORAN C units were available on the civilian market. Gen-Av snapped them up. Genav units included many very useful Genav features. One of many was continuous speed & direction info. Based on the DR system (No. 2) it was easy to compute with the E-6B the wind velocity since the Aero Navigator had heading & TAS information. Thus, if a course change proved necessary, the W/V info could be used to quickly establish the new heading value, including W/V correction. Not knowing W/V he'd just have to guess at TH, to maintain the TC he wants to fly. Another valuable feature was "Nearest Airport". If a flight did not progress as expected, & a fuel stop proved advisable, the nearest airport feature could be selected. If the nearest airport proved to be too large or too small to suit the Aero Navigator he could select the next nearest. If that airport was too far off course to suit, the third or fourth nearest one could be selected. In any case, the information included some pertinent airport data. If additional data were needed, that could also be called for.

The LORAN C, including the receivers & theory, & the fascinating & challenging LORAN operational procedures are discussed in great detail in the appropriate subsequent Aero Navigation system.

D.c.i Radar

Radar, as used in aircraft, is specialized:

One type is used for map reading even if flying over clouds;
Another for collision avoidance;
One for terrain clearance;
Still another for storm detection;
Each of these Radars is applicable to a specific type of Radar.

D.c.j GPS

The GPS was made available for aviation use well after military applications. Gen-Av GPS systems were introduced in the late '80s. Ten years later manufacturers designed units for the automotive & hiker market.

The GPS, including the fascinating & challenging GPS instrument approach procedures are discussed in great detail in the appropriate subsequent Aero Navigation system.

D.d Time as Applied to Aero Navigation

If crossing time zones, it would be confusing to use the time zone that plane is flying in at the moment. But so would weather forecast, etc. Time zones & CDT vs. CST might result in uncertainty that might result in arrival 30 minutes before the ceiling is forecast to lift to VFR or IFR minimums, depending on the type of flight plan. This point of confusion is eliminated by using "Zulu" as a standard time for all aviation communications. Zulu is the official slang for GMT (Greenwich Mean Time); the time in Greenwich England. This is, in fact, the zero longitude meridian. The East coast of the U.S. is 5 hours behind Zulu except when stating time in EDT (Eastern daylight time). So at the time of noon in NYC, the official time is 1700 Zulu; actually 5 p.m. in Greenwich England, except that time is always stated on a 24 hour clock; neither a.m. nor p.m. The time difference is then 6 hours for CST, 7 for MST, & 8 for PST. It is always safer to keep the aircraft clock set to Zulu, even if using an analog clock with 12 hour display instead of 24 hour. Zulu is only in true time; never daylight savings time.

Time for celestial navigation is even more complex & requires 1 second accuracy. See paragraph 4. & 5.

D.e Aero Navigator.

Most small planes, including fighter aircraft, obviously have never had the luxury of a full time navigator. Before the mid 1950s an Aero Navigator was a necessity for long overwater flights in large aircraft. Navigators have largely been displaced by modern avionics that allow the pilot to more readily perform all necessary Aero Nav functions. The FAA still "has" a flight certificate (license) for Navigator, & the USAF, until recent years trained & issued "wings" to Navigators, but modern Aero Navigation systems have virtually eliminated the need for a dedicated Navigator, even on long trans-ocean flights by large aircraft.

There were 624,000 pilots (are also qualified to navigate an aircraft) in the U.S. as of 2007, most of whom are classed as part of "General Aviation". Gen-Av consists primarily of pleasure & business flying; all pilots except military & airlines. Nearly all multimillion dollar biz jets, & many of the largest jets, are devoted to corporate use; thus qualifying as part of the Gen-Av community. There are approximately twice as many private pilots as commercial pilots. Approximately 300,000 pilots are instrument rated. Nearly all commercial rated pilots have an instrument ratings.

The term "commercial" does not imply that the pilot is always paid for his services; in fact, many pilots obtain advanced ratings to improve proficiency, & to better understand the aircraft & flying in general. Some activities are not permitted with a commercial license. Some commercial pilots never actually fly for hire.

Conversely, a private pilot is allowed to serve as the "company pilot" if his salary is "primarily" based on activities "other than flying". Of course, all airline pilots "were" instrument rated, although when a pilot obtains an ATP (Airline Transport Pilot Rating) the Instrument Rating is removed from his license.

The ATP still includes the "authority" to fly instruments, of course. The number of instrument rated pilots has been increasing over the years, as the IFR system was improved & simplified. Many, if not most, instrument rated pilots do not actually enjoy instrument flying, since it is rigorous & demanding. Some instrument rated pilots admit that they fly IFR only to climb or descend through a cloud deck, preferring VFR on top, even if filed for IFR. The author is one who thoroughly enjoys every type of flying he's tried, including IFR. He routinely flies 6 or 7 consecutive hours, or occasionally twice that, after a refueling stop, while "in the soup" (engulfed in clouds) from take-off until near the ground on landing approach. He has always "filed" IFR (see note 1 below) for "mid cloud height", when practical, to increase the probability of remaining "in the soup" for the entire flight, to maintain proficiency, gain experience, & simply to enjoy "solid soup" IFR flying. It is certainly more pleasant & rewarding than to fly with an awkward IFR practice hood. A better option than the hood is to modify a pair of plastic safety glasses to obscure the view outside of the cockpit. IFR is easier & more pleasant in a good stable "platform" such as the authors Cessna single engine lightplane. Some of the 45 "types" that he's flown certainly would not have been pleasant to fly IFR, even though all were a joy to fly VFR. Some were quite a challenge to fly under some circumstances, or to land, even though landing is one of his greatest pleasures in flying.

Note 1: An IFR flight plan should always be "filed" before entering IFR conditions. If essential to wait until airborne to file IFR, he must either obtain pre-approval or remain under VFR conditions until cleared to proceed.

APPENDIX E: Costs Not Previously Discussed

E.a Insurance

Even renters should have non-owner insurance. Most FBOs do not totally insure the planes against damage by a renter. Without it, the renter may owe the FBO the full price of a plane.

Insurance rate decreases as total flying time & time in type builds. Additional ratings & licenses also reduces rates. Most important is to find an insurer that has no serious loop holes. Violation of FARs, inadvertent failure to fly out of medical or license, & simple stupid or careless flying are disqualifiers for some insurers. If so, why bother. Most accidents involve some degree of carelessness or incompetence. The author's insurer assured him that they had no such exclusions. They insured his plane for a fraction of the cost of the insurance for his sporty Camaro V6 manual shift Chevrolet, that was worth a fraction of the value of the plane. Specifically full coverage was $300 per year until inflation resulted in creeping up to $500 per year.

Insurers generally define a partnership as no more than 3 to 5 members; more constitute a club. Club insurance rates are several times that of individual or partnerships.

Partnership rates depend on flying time of the lowest time member. A fair cost breakdown would seem to be to allow each member to pay his share of the cost. A hypothetical example might have 2 pilots with 1,500 hours each, & a zero time student. The 1,500 hour pilots might pay $500 each per year if sole owners. The student rate might jump to $1,500, if sole owner. That ratio may be the best cost assignment for a partnership. If total insurance rate is to be $2,000, the cost assignment should be $400 each for the high time pilots, & $1,200 for the student. If however the individual high time pilots can pay only half of a 2 man partnership; or $250, as is usually the case for a 2 man partnership, then the student should pay $1,500. In any case the student insurance rate will drop as he builds flying time.

E.b Cost to Store a Plane:

Unless the owner has direct access to a runway, or a very large pasture, the plane must be towed home (impractical for most planes), or tied down or hangared at an airport. Tie down & hangers vary greatly with region & airport. . Tie-down on 1 excellent small town Houston suburb airport is now $40 per month; while hangar rent is $350. A much nicer & newer hangar on a larger, better equipped airport in a Phoenix suburb rented for the same as a rundown hangar in that Houston suburb. Both hangar & tie down rates vary significantly across the U.S., & even across the airport. Typical tie down range "might" range between $10 (a few FBOs offer free tie down if their fuel & repair facilities are used) & $100 per month; hanger $50 to $1,500. Hangers are always preferred, but nearly essential for composite planes (**see note 1. below**), & much better for wooden or fabric covered planes. One of the many merits of all aluminum planes is their ability to withstand UV & weather better than any other material of construction. The author once tied an aluminum plane down for 20 years, only 4 miles from the salt water of upper Galveston Bay; with virtually no corrosion. Then stored in an "open T hanger" (cover only) for another 18 years in the same location. Older fabric covered planes required a recover very few years until the introduction of modern materials that last for many years.

Note 1: Having served as "the composite expert" for one division of one of the largest companies in the U.S., the author is aware of some significant weaknesses of composites. Homebuilt composites are rarely formed under heat & pressure. If the sun warms them above the temperature of the product during the curing process, they lose strength, & increase the risk of structural failure. Homebuilders do not have access to an autoclave, although some do, indirectly, by buying major structural components from a kit manufacturer that does have access to an autoclave. Not all kit manufacturers do, however, so that is a critical question to ask.

E.c Avionics & Tool Cost::

The GPS finally hit the Aero Navigation Equipment list as soon as 24 satellites became fully functional, in the mid 1990s, & became the new "wonder" Aero Navigation system. It became incredibly important for pilots from that point on. One of the best by 1996 was the handheld Garmin 195 with small B&W screen for the moving map & data galore; for $1,200. Color has since dominated, but B&W is still available.

Airborne avionics can be relatively inexpensive; or extremely costly, depending on the type of avionics, plane and intended use. Aerobatic planes & sailplanes generally carry a bare minimum of "radio equipment". For some planes & usage, there is actually no need for Aero Navigation related avionics; or even communications. Simple map reading with dead reckoning will suffice. For many applications a hand held Navigation-Com is satisfactory. A hand held Navigation-Com offers OMNI for Aero Navigation & communication transceiver in a 1 to 2" thick package; otherwise not radically larger than a hand held engineering calculator; typically less than $300 new. They are obviously not allowed for IFR flight. Panel mount & IFR approval is necessary for IFR flight.

E.c,a Essential Aero Navigation devices for any Pilot:

The "old fashioned" E-6B is quite adequate, & should always be available even if an electronic E-6B is available. Only the old mechanical E-6B never fails: cost $13 to $30. [The Electronic E-6B or equivalent (much like typical hand held Engineering calculator) is a nicety that most pilots do not purchase: $70]. Weems plotter: $5. Total cost for essentials: $18.00. Eventually he will need at least 1 Sectional chart for $8.

Both IFR & VFR pilots require current Sectionals. A typical 1,000 mile flight might require 3 Sectional charts at a cost of $8.00 each for VFR flights; approximately $24.

For that flight under IFR conditions he needs not only the Sectionals, but also approximately 3 sets of approach plates at a cost of $4.25 each & 3 enroute charts at $4.10 each. A total of $25.05 plus the Sectionals; $49.05 for that hypothetical flight. The actual number of each depends on the specific location; it may require a chart that ends a few miles after departure. The IFR pilot must also spend more on proficiency flying. Unless he flies enough actual IFR to maintain proficiency & currency he must also practice IFR with a licensed "Safety Pilot" who has been checked out in the type of plane flown; in the seat beside him. Such safety pilots often fly free for a little stick time. He will need a hood. The IFR practice hood is bulky & lasts "forever", but after tiring of trying to keep up with it, the author made a handier substitute from a pair of plastic safety glasses. A little sandpaper or paint to obscure a portion of the lenses, & a Dremel to cut away areas through which to view instruments, proved to be much more practical.
Many pilots also prefer to have handheld GPS & Navigation-Com as back-up.

E.c.b Optional Avionics for the Renter or Club Member:

Optional avionics devices include the handheld Navigation Com & hand held aviation GPS. Only a GPS that was designed for aviation type is of any real value in flying. Portable LORAN is not available; impractical because of the very large ground plane that is required.

Rental & flying club planes must have a legal minimum of avionics for the category of the aircraft, & nearly all will have at least 1 panel mounted OMNI based Navcom. Virtually all will have a transponder & a mandatory ELT, so neither renters nor flying club members actually need hand held avionics. A few pilots do prefer to have their own handheld

Navcom (OMNI based plus transceiver) &/or a handheld GPS with a small moving map display. There is little justification for club member or plane owners to buy hand held Avionics if the plane has panel mounted, but a few aircraft owners do buy a hand held portable Navcom to cover emergencies, such as total electrical failure. An indication of the "approximate" cost of these "optional" navigation tools & avionics is given below: A hand held Navcom usually cost about $300. Icom A14 Handheld COM Transceivers start at $165; $250 for handheld Navcom.

Hand held GPS units are available in a very broad range of price & capability, including an updatable very elaborate aviation data base; an example is the Garmin GPSMAP 695 with 7" screen for $2900. The data base includes detailed IFR charts. The smaller screen, less capable GPS MAP 495 sells for $1700. GPS MAP 296 color handheld sells for $750 rebuilt from Gulf Coast Avionics; one of several reputable sources for avionics. Most later models of GPS offer more features than the $1200 1990 Garmin 195 predecessor.

As of 2009, the moving map handheld Garmin 369 color map with XM Weather radio & obstacle & terrain alerting is $1600. Some say the top quality handheld available GPS with large (5 x 7") color moving map is the Garmin 696 with XM weather radio & obstacle & terrain alerting: $3500. Total cost for excellent avionics starts at $680.00.

E.c.c Panel Mounted Aero Navigation Devices (& Cost) for a Plane Owner:

In recent years the prices of aircraft have skyrocketed, so most "would-be individual plane owners" seriously consider used planes or partnerships. The ELT & Transponder are required under most circumstances for all aircraft that were certified with an engine driven generator & electrical system. Nearly all planes will include at least 1 OMNI based Navigation-Com. Many are IFR equipped with dual Navigation-Com & a few other items; possibly even a panel mounted GPS, or GPS with integral OMNI & Com, glide slope receiver, ADF, etc.

Total cost of adding avionics to a used plane will obviously vary: Some examples for cost of panel mounted avionics: An Ameri-King ELT model AK-450 costs $140, & the Narco Transponder starts at $1,200. Used avionics are typically half price.

A few examples of panel mounted GPS units are typically over $5,000:

If he wants a new plane, he will usually have a choice; although factory "basics" are adequate for most needs.

The "cost to certify a panel mounted GPS for IFR" can be half as much as the unit proper. Because of the exorbitant cost of the "panel mounted" GPSs many pilots use handhelds in their own planes. The IFR certification cost & FAA certification requirements for each individual plane were similar for the LORAN-C, although the LORAN-C was never manufactured in handheld units. This is because a LORAN requires a large "Ground Plane" which demands even greater equivalent area than an automobile can portray.

Many "used" certified planes are complete with "appropriate" avionics, though some may be out of date or not be the latest avionics. "Appropriate" may mean only a mandatory ELT, & Transponder, or a great deal more, depending on how "serious" the buyer is (as well as the previous owner was) about long range flying, & especially "heavy" IFR. The ELT & Transponder are required under most circumstances for all aircraft that were certified with an engine driven generator/alternator & electrical system. Nearly all planes will include at least 1 OMNI based Navigation-Com. Many would have dual Navigation-Com & a few other items; possibly even a panel mounted GPS, or GPS with integral OMNI & Com, glide slope receiver, ADF, etc.

For VFR a second (Dual) Navigation-Com is useful, & increases safety. It is not prudent to fly IFR without dual Navigation-Com. An example of usefulness includes the ability to obtain 2 LOPs simultaneously for a fix as opposed to only one LOP at a time. Obtaining 2 separate LOPs using a single VOR is inconvenient & subject to timing errors since the plane will move between LOPs. Another is when it is desired to preset a transmitter for convenience; or to alternately select 2 different frequencies. An example of safety is redundancy for the sake of avionic failures. Other manufacturers recently caught up with Collins by adding the equivalent of the Microline dual selector. The Com transceiver could be set to the expected frequency & then after storing that, the next freq could be selected. It took an instant to rotate the coaxial selector knob 30° to switch between the 2 frequencies. At any time one freq could be changed to any other value. Dual Collins NavComs provided any of 4 com frequencies in an instant. The Collins Navigation receiver could display the OMNI bearing digitally or on the analog CDI. Panel mounted second (Dual) Navigation-Com is almost essential for IFR operations, but an ADF, & Loran or GPS adds greatly to safety & convenience. The 2009 cost of a typical IFR avionics package typically ranges well above $12,000; often $35,000..

During the 2000s some major advances were made in avionics. ARC, Collins, Terra, & Garmin in particular offer amazing capability for moderate prices, if the pilot can spare $10,000 for an advanced avionics system. Terra offers an assortment in a small package & a few panel mounted units. Garmin MFD continuously (if called for) displays an endurance circle that encompasses all points that a plane could reach before reaching a 45 minutes fuel reserve; & even expands that irregular circle to include those it could glide to with empty tanks. The consideration for dead stick landings is indicative of the gliding capability of modern jet planes. After all, the space shuttle glides several thousand miles after re-entering the atmosphere to land on a very short runway considering the gliding distance. This is actually an irregular circle because it even adjusts for winds aloft. It is vastly easier than when the author wrote a complex computer program to develop a spread sheet to carry on an overwater flight, so he'd know, based on reported winds aloft reports, which way to fly if he lost power at 14,000' between Florida & Grand Bahama Island. If all went well, except for an engine failure, he would have had only a 14 mile stretch where he'd have been out of gliding range of one shoreline; had to ditch. His information was limited to old winds aloft info, while the Garmin MFD instantly updates.

Airborne avionics can be relatively inexpensive; or very costly, depending on the type of plane and intended use. For some planes & applications, there is actually no need for Aero Navigation related avionics; or even communications. Simple map reading with dead reckoning will suffice. For many applications a hand held Navigation-Com is satisfactory. A hand held Navigation-Com offers OMNI for Aero Navigation & communication transceiver in a 2" thick package; not radically larger than a hand held engineering calculator; typically approximately $300 new. The more serious the Aero Navigation & travel, the more extensive & expensive the Avionics required; in many cases many tens of thousands of dollars. There is, however, a very large market for used avionics, so it is possible to equip a plane for half the new value; usually with a warranty. For very serious IFR in a S.E. (single engine) Gen-Av lightplane $10,000 is an absolute minimum, & $20,000 is more likely new price since the year 2000. $20,000 would have paid for an exceptionally well equipped IFR S.E. lightplane in 1980. As of 2009 it is difficult to equip a bare minimum lightplane for IFR for less than $15,000.

E.d Cost of Access to an Airplane:

E.d.a Rental:

Total hourly cost of a partnership or club may not be radically less than a rental. It depends on how well organized the club or partnership is financially, & how many hours per year he will fly.

Rental rate is actually exceptionally low considering the value of the plane. A plane valued at $30,000 typically rents for less than $50 per hour. Compare that with tool rental, where a few days rental would often pay for a new tool. Even then it does add up quickly for obtaining a license & maintaining proficiency. Maintaining proficiency is not just a nicety; it is mandated by the FAA, as well as being a safety issue. A new private pilot's proficiency drops off very quickly. After a few hundred flying hours proficiency is more easily maintained, but frequent flying is still important.

The new pilot does not recognize his mistakes well, but soon learns to identify them. After he has a few hundred or thousand hours, he may be very disappointed if he can detect the moment of touchdown by anything except the sound. If he then drops back to 20% of the flights per month, he should quickly identify a drop in proficiency.

An advantage of FBO rentals is that the optimum plane can be selected for each flight; light twin or high performance SE for long trips, moderate performance plane for short trips, aerobatics, or lowest cost for local joy riding. Proficiency is again a consideration. A bit of light twin time keeps a pilot sharp for a Cessna 150, but not quite so much for reverse.

E.d.b Sole Ownership

To use a typical moderate sized Cessna for a cost example: Buy it used for $35,000. Pay $30 per month tiedown or $175 per month hangar rent. Pay $500 per year for insurance. Pay $300 per year for an annual by helping the mechanic. Change oil at $2.50 per quart & 6 quarts per change; once per 25 hours of flying. Pay $3.50 for gas at 6 gph. Fly 10 hours per month at 125 mph. TAS.

Total cost per year at 100 hours per year: $30 + $500/12 + $300/13 + $2.50 x 6 x 10/25 + $3.50 x 6 x 10 = $310.74 per month = $3,728.92 / year. Hourly cost $37.12 per hour. A little less than FBO rental. Total distance flown 12,500 miles.

If he flies 50 hours per year that becomes $30 + $500/12 + $300/13 + $2.50 x 6 x 5/25 + $3.50 x 6 x 5 = $202.74 per month = $2,432.92 / year. Hourly cost $$48.66 per hour. Still a savings vs. FBO rental. Total distance flown 6,250 miles.

Sole ownership is likely to be the most expensive for pilots who fly very seldom because the fixed costs, such as hangar (or tiedown), annual, & insurance are not shared. If it is flown a large number of hours per year it will usually be the least expensive option. Depending on the degree of activity, rental from an FBO may be the least expensive.

The owner may not perform “work” on his plane without supervision of a certified aircraft mechanic, & that includes the “annual proper”, & installation of new equipment; unless he is also a certified aircraft mechanic.
The many benefits of sole ownership include absolute access; day or night, even for a short notice, one month long trips. Unlimited control over all decisions, such as hangar vs. tiedown. Total freedom to select avionics & other accessories.

Beechcraft & Cessnas in particular very rarely need any maintenance at all to remain in like-new condition; indefinitely. So an annual rarely offers any big surprises or expenses. An indication of maintenance cost & potential for mechanical problems on trips, is the number of AD Notes (FAA Airworthy Directives) on it vs. other planes. The Cessna stack of ADs is literally 10% of the size of one major competitor. Ask a mechanic to show his AD files for planes of interest vs. your second choice. Obviously the older planes will have had more time for ADs to be developed, so that should be considered in the analysis.

An annual inspection for a SE, FG, FP prop Cessna can be as low as $100 if the owner assists, if nothing major is found, & on Cessnas that would be extremely rare. Assisting with the annual is a good way to learn more about the plane, & to improve the ability to detect problems between annuals. If the owner does not assist, the cost may be $300. A very reliable, high performance Beech Bonanza is also quite costly, because it is considered the Cadillac of the Genav fleet. The Beech Bonanza is undoubtedly an outstanding plane. A direct comparison of several Pipers & comparable type Cessnas indicated that the Piper annuals cost between 5 & 10 times as much for several years.

Engine overhauls generally top $10,000, but often last 2,500 hours for private use; 2,000 is typically mandated for commercial use. Pilots generally fly fewer than 100 hours per year, so 2500 hours represents many years of trouble free flying. If the plane is used for hire, an inspection must be performed every 100 hours. If solely for personal use (not renting or carrying cargo or passengers for hire) an annual is allowed. Annual is actually even better in that the annual expires at the end of the month it was last inspected, so often it is actually performed every 13 months.

Like many previously owned items, it is much more economical to find a plane equipped as desired than to add avionics or rebuild the engine.

E.d.c Partnership or Flying Club

It is obvious that the fewer the members in a partnership, the less advantage there is to adding members. Likewise, access is limited as more members are added. Cut costs in half, thirds, or fourths. Scheduling is not likely to be a problem even for 4 partners.

Many thousands of pilots in the U.S. wholly own a lightplane, possibly even more own part of a plane via a partnership of 1 to several planes, & many join a flying club. Many simply rent. A partnership is typically on a single plane. Adequate for most pilots. A club sometimes has the advantage of several planes. For a new student that’s not much of an advantage, but it may be in a few months or years. For a high time pilot who enjoys playing around on a week end, but a serious IFR capability for XCs, it is a great advantage. The most important thing in a partnership or club is a proper cost balance. Each member should pay his equal share of hangar, annual, & insurance; fixed costs in the form of monthly dues. But each should pay proportional to flying hours for time in the air. Hourly rate should cover costs that vary with time flown, such as oil changes. It is only fair for the pilot who flies 200 hours per year to pay much more than the one who flies an hour per month for engine overhaul allowance, as well as fuel cost. Fixed & hourly costs must be computed into the member’s hourly cost of flying. Most costs vary with aircraft size & value, & more importantly, with location.

It is very important to analyze the financial aspects of any club or partnership. Often some members end up subsidizing others.

E.d.d. Flight Physical (Medical):

A flight physical is required every 5 years before the age of 40; then every 2 years for private pilots. Some flight surgeons charge $50 per physical; some $500 or more. LSA may be flown using only a driver’s license, once the pilot has passed a flight physical; as long as he has not failed the most recent one. This may sound confusing, but that is the rule.

E.d.e BFR (Biannual Flight Review):

A BFR is necessary for all except ultralight. So no matter how many hours, ratings & licenses a pilot has he must take a BFR every 2 years. BFR requires 1 hour of flying plus 1 hr of ground questioning & training. At a time when auto gas is $3.00 per gal & Av-Gas $4.00, dual in a small trainer such as a Cessna 150 would cost $100 to $200 total for VFR; a little more for IFR, depending on location. If the "student" pilot provides the plane, the cost would only be 2 hours of CFI time at $20 to $50 per hour typically, + fuel + aircraft "variable operating allowance" for 1 hour.
The instrument rating does add to the cost in terms of equipment (avionics) required. An instrument rated pilot must include demonstrating IFR competency during the BFR to maintain the right to fly IFR. A local FBO could tell you exactly the cost at his location, & plane rental & CFI rates.

APPENDIX F: Impact of the Atmosphere

F.a What Causes lift? Several incorrect theories are frequently reported in assorted sources. The fact is (per NASA) that lift results from a combination of 2 basic forces. The upper airfoil surface is curved such that it causes air to speed up as it passes over the wing, thus Bernoulli's Principle states that pressure decreases as velocity increases, so lift is generated by causing a small vacuum relative to ambient pressure. Since most flight occurs with a positive angle of attack, air flowing under the airfoil is deflected downward , which results in a response per Newton's Third Law (of action vs. reaction); wing experiences an upward force (lift) equal to the downward force exerted on the air. Lift is always the result of a solid body causing a displacement of a static fluid. In this case the fluid that is deflected by the solid wing is air. The fact that air may be moving is not a factor re the static fluid. In fact, a wing moving thru the air is not impacted by the movement of air; wind, unless the wind gusts. A jet plane flying in the Jet Stream may be flying at 400 mph while being boosted by a 200 mph jet stream. It maintains a ground speed in this example of 600 mph, even though the Mach Meter or True Airspeed indicator shows only 400.

Wing lift does seem to be greater than one might imagine from a low density substance such as air. A look at any plane indicates the actual value. Wing loading (WL) is given in psf; pounds per square feet of wing area. WL is based on max gross weight, so the actual lift is normally less than specified. The fast, modern Piper Malibu has a WA (wing area) of 175 square feet & max gross weight of 4,100 lb., giving a computed WL of 23.43 psf. Piper seems to base specified WL on a slightly lower gross weight, & calls WL 22.3. That is thus 0.15 psi, so it really is quite a low pressure differential.

The wing lifting power is directly related to the air density. This relationship is defined by the simple equation:

$C_L = (L) / (A)(0.5)(r)(V^2)$

Where C_L = coefficient of lift, which is determined experimentally,
L = lift in pounds,
A = wing area in square ft.,
r = air density in slugs/ cu ft,
V = speed through the air in mph.
C_L is impacted by Reynolds number, which is the ratio of inertial forces to viscous forces. The Reynolds number is = [6,000] [speed)] [wing chord], where the units of speed is ft/sec, & the units of chord are ft. Flying Model planes are subjected to the same Reynolds number equation, so "scale effect" is critical in enlarging or reducing the size of any given aircraft. EAA Homebuilders have occasionally scaled down the P-51 & several other popular planes. A 2 / 3 scale P-51 replica with 10% of the engine hp still performs quite well; though it is not as fast as the full sized P-51.

Transposition of the above equation for C_L produces the equation for lift:

$L = (C_L)(A)(0.5)(r)(V^2)$

Lift must be constant at aircraft gross weight in order to maintain level flight. Lift must exceed gross for the plane to climb. For the plane to climb, the only variables in the equation that may be increased are C_L & speed. As the plane climbs, decreasing air density reduces lift, so corrections must be made to maintain adequate lift. Power increase may permit increase in either the speed or the angle of attack, but the norm is for climb speed to be considerably lower than cruise speed. Thus coefficient of lift must be increased even more. Excess power then is consumed in lifting the plane (excess lift); a climb.

Since power is limited, the most practical way for a specific plane to climb is to increase power slightly & more importantly the angle of attack of the wing. Fig F1 illustrates the relationship between C_L & angle of attack. The angle of attack is the angle between the "relative wind" & the mean chord line of the airfoil. The mean chord line of the airfoil is a line between the stagnation point on the large radius leading edge to the sharp trailing edge of the wing. . The stagnation point is the point along the leading edge curvature of a wing where the oncoming air separates into upward or downward flow. The **relative wind** is horizontal for level flight cruise. In a climb the relative wind is not horizontal, but inclined, as though the plane were flying up a ramp. Angle of attack should not be confused with the angle of incidence, which is the angle between the longitudinal centerline of the aircraft & the mean chord centerline. The angle of incidence is commonly pitched up; as though in a shallow climb.

There are numerous different airfoil designs; each has its own distinct characteristics, including the shape of the C_L vs. angle of attack curve. Only 1 airfoil design is illustrated in Fig F1.

This curve shows that an angle of attack of 16° gives the max C_L of 1.72, which is the point where the C_L begins to decrease, so operation well before 16° angle of attack is desirable, unless the object is to stay in the air as long as possible. Planes do have a max glide distance IAS, so that in case of power loss & a need to "stretch the glide". Stretching the glide is a misnomer. Gliding dead stick (engine dead) at magnetic glide speed optimizes distance over ground to touchdown. If a little short the natural tendency is to ease back on the stick or wheel, but that is very likely to result in a stall without sufficient altitude to recover; a very serious & dangerous situation. It will also decrease chances of reaching the desired touchdown point.

Assume that the C_L - Angle of Attack curve of Fig F1 is valid for a plane having a 170 sq. ft. wing area, a gross weight of 3,000 lb, & cruises at 150 mph IAS at SL with an angle of attack of 1°.

The equation for determining C_L of this plane is:

$C_L = L / (A)(0.5)(r)(V^2)$.

r = air density in slugs / ft^3 as read from the Standard Atmosphere table.
For this analyses, r = 0.002377 at S.L., 0.00164 at 10,000', & 0.00109 at 20,000'.

Applying the above C_L equation to the above hypothetical airplane at S.L. at 3 altitudes:

$C_L = L / (A)(0.5)(r)(V^2) = 3{,}000 / (170)(0.5)(0.002377)(150^2) = 0.660 = C_L$.

Fig F1 shows the C_L – Angle of Attack curve indicates an angle of attack of 1.00°.

What must the C_L be at 10,000' if the speed is maintained?

$C_L = 3000 / (170)(0.5)(0.00164)(150^2) = 0.956 = C_L$.

The C_L – Angle of Attack curve indicates an angle of attack of 4.00°.

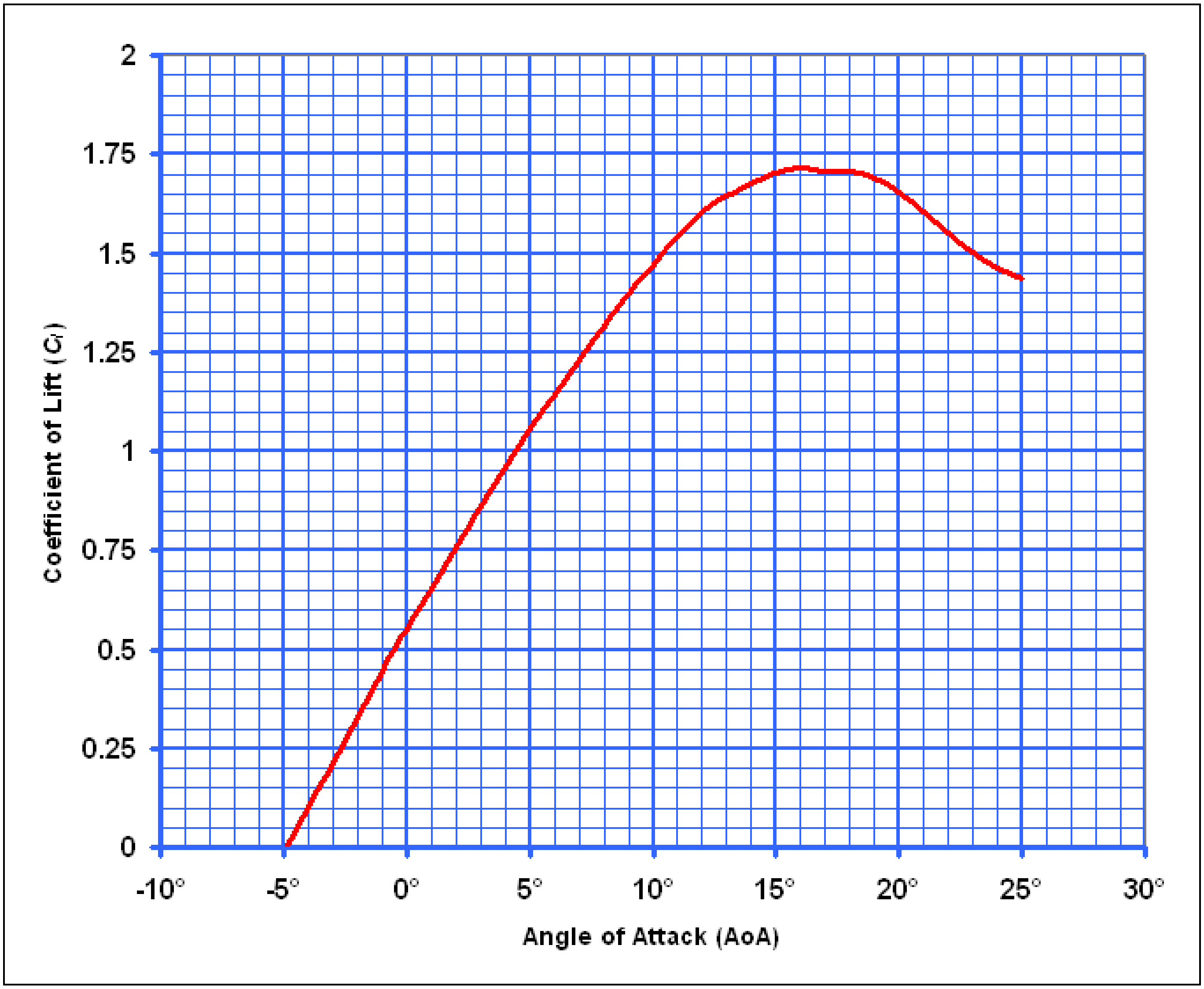

Fig F-1 - Lift Curve of a Representative Airfoil

If the plane has enough power, & is equipped for higher altitude flight, & the pilot chose to climb to 20,000', the C_L = 3000 **/** (170)(0.5)(0.00109)(150^2) = 1.439 = C_L.

The C_L – Angle of Attack curve indicates an angle of attack of approximately 9.4°, which is quite a high angle of attack for cruising flight. Most airfoils used on lightplanes stall between 18 & 20° angle of attack, so 9.4°, is still a practical angle of attack.

The Angle of Attack could be reduced if power is sufficient for higher speed cruise; possibly if equipped with a turbocharged engine.

Given a turbocharged engine, the performance might be closer to 180 mph at 18,000', C_L = 3000 **/** (170)(0.5)(0.00109)(180^2) = 1.00 = C_L. Thus the Angle of Attack at 20,000' altitude might be near that at 10,000'; 4.4°**.**

Very few single engine lightplanes can reach such a high altitude as 20,000' without a turbocharger. The normally aspirated high performance Cessna 210 described in this example has a service ceiling of 18,300'. The turbocharged version has a 27,000' service ceiling. Absolute ceiling would be a little higher, but service ceiling is defined as the altitude at which the plane climbs at only 100 ft per minute. Since there are sometimes extensive atmospheric disturbances at 20,000', it is necessary to be able to climb quickly back to the assigned altitude in the event of a downdraft. Cruising above the "service ceiling" is thus undesirable. All flight above 18,000' must be under ATC control, so altitude fluctuation will result in a call from Center to immediately return to the assigned altitude.
Thus as altitude increases, & air density decreases, the ability to lift relies on a higher angle of attack since additional power is not necessarily practical. So TAS decreases as IAS drops severely as angle of attack increases. Just how

fast do air density & pressure drop off with altitude? Exponentially, because of the nature of the impact of gravity & buoyancy. Equations can be developed from the Ideal Gas Law, & calculations indicate the following:

The Standard Atmosphere					Fig F-2
Altitude ft	% of Atmosphere	Pressure in. Hg	PSI	Mass Density Slugs/cu. Ft.	Remarks
0	100	29.92	14.7	2.377x10E-3	Mean Sea Level
1,000		28.86	14.17	2.29 x10E-3	
2,000		27.82	13.66	2.21x10E-3	
3,000		26.82	13.17	2.13 x10E-3	
4,000		25.84	12.69	2.05 x10E-3	
5,000		24.89	12.22	1.98 x10E-3	
10,000		20.58	'10.10	1.64 x10E-3	Max Altitude without Oxygen
15,000		16.88	8.29	1.34 x10E-3	
18,000	50	14.94	7.34	1.19 x10E-3	Lowest Legal Flight Level
20,000		13.75	6.75	1.09 x10E-3	
25,000		'11.10	5.45	8.82 x 10E-4	
27,480	33	9.97	'4.80	7.92 x 10E-4	
30,000		8.886	4.36	7.06 x 10E-4	
40,000		5.538	2.27	4.40 x 10E-4	See below for author experience
50,000		3.425	1.68	2.72 x 10E-4	
52,926	10	2.992	1.47	2.38 x 10E-4	
100,000		0.329	0.16	2.61 x 10E-5	
101,381	1	0.299	0.15	2.38 x 10E-5	
159,013	0.1	'0.030	0.001	2.40 x 10E-6	
227,899	0.01	0.003	0.0001	2.40 x 10E-6	
283,076	0.001	0.0003	0.00001	2.40 x 10E-6	
327,000	Generally accepted as the altitude where space begins				
450,000	Approximately the altitude where Re-Entry vehicles begin to glow & ablate				
Note: Standard Temperature lapse rate is 5.4° per 1,000', & Pressure decrease is 3% per 1,000'.					

Fig F-2: Standard Atmosphere

F.b The Standard Atmosphere

See Fig F-2 for the Standard Atmosphere & related information.

F.c Characteristics of the Atmosphere that impact Safety of Flight, & the Resulting Controls: Permissible Altitude of Flight

18,000’ is the point where jet “Flight Levels” begin. The term “Flight Level” is used instead of altitude starting at 18,000’. VFR may not be “filed” at or above 18,000’. Altimeters must be set to the nearest known altimeter setting below 18,000’. The “unit” of measure of the adjustable altimeter setting is “inches of mercury”. Altimeter setting in inches of mercury is set into the Kohlsman; standard being 29.92. This “setting” is important because the local changes in ambient pressure cause changes of indicated altitude which would increase the risk of mid-air collisions; or even into a mountain during cruising flight. Nearly as important, it would result in entering the traffic pattern at an incorrect altitude, requiring an exceptionally high or low glide angle during the landing approach; which increases the risk of undershoot or overshoot.

Because of the higher speed of aircraft flying at very high altitudes, more frequent altimeter setting changes would be inconvenient, & the higher power of jet aircraft altitude ease the problem of changes to correct for vertical currents.

A critical solution is to allow all planes in the flight level regime to follow the indicated MSL altitude assigned. This is accomplished by setting all altimeters to 29.92 when flying above 18,000' MSL. This, of course, will result in moderate changes in absolute altitude, as pressure actually changes. All planes must follow the "assigned set altitude", which will result in changes in absolute altitude as atmospheric pressure changes.

45,000' is the max altitude the author has ever experienced; as a passenger in a moderate sized twin engine jet over Europe. The sky during daylight hours actually looked extremely dark blue because the atmosphere that absorbs light to give the sky its color was reduced to 18.5% of the sea level value.

F.d Atmospheric Impact Upon Aircraft Engines & Aerodynamics

Fig F-3 illustrates the influence of altitude upon the Cessna 210 that will be discussed below and has the following IAS vs. TAS for various altitudes, based on pressure lapse rate & the Cessna 210 flight manual, & selecting the highest listed cruise power in the flight manual. A plastic "Flight Performance & Power Computer" provided with each plane permits selecting intermediate power settings. It is also much more convenient than a manual in the cockpit in flight.

Fig. F-3: Aircraft Performance vs. Alttiude; Cessna 210RG

Altitude	Temp. °F	% Power	TAS	IAS	TAS/IAS	Max Power C.S. Prop	Max Power F.P. Prop	Range at these conditions (& max)
2,500'	45.5	70	176	171	1.048	93	91	1070 (1310)
5,000	32	72	184	173	1,089	85	82	1090 (1335)
7,500'	18.5	71	190	172	1.138	78	74	1,135 (1355)
10,000	5	63	184	176	1,187	71	86	1,235 (1,360)

CS = Constant Speed Prop; F.P. = Fixed Pitch Prop (ref only; not on 210)

Fig F-3 Aircraft Performance vs. Altitude

The data in Fig F-3 are based on a "standard day"; 59°F at S.L., & the 1968 Cessna 210 flight manual. Note that both pressure & the max engine power of a normally aspirated (neither turbo nor supercharged) reciprocating engine drop in proportion to pressure drop at a rate of 3% per 1,000'.

The max horsepower possible is directly proportional to atmospheric pressure, & inversely proportional to the Absolute Temp. The absolute temp, then has a minor impact, since the "base" is a large number (459.67°F; ref Rankin). The 210 used for this illustration is powered by a 285 hp, 520 cu in. 6 cylinder Continental air cooled engine that will typically fly 2,000 hours or more with no failures & very few, if any, problems requiring unexpected maintenance.

The performance data on the Cessna 210 given in Fig F-3 does not mention that the 210 can climb to 15,000' in as little as 15 minutes at 100 mph IAS & greatly reduced forward speed. A cruise climb to 15,000' at "cruise-climb speed" (120 - 140 mph IAS) may take 45 minutes. If a pilot only wants to fly a distance of 100 miles, it is unlikely that he would climb to more than 5,000'. It is most economical to evaluate the time to climb, optional climb speeds, & winds before selecting cruise altitude. Likewise, the last column shows range vs. altitude, which gives another indication of the merits of flying high. Range generally increases with altitude.

Note that most pilots fly either conservatively (50 to 65%) to reduce fuel consumption, & significantly extend engine life (potentially double life), or at the max recommended power of 75%. A few even cruise above that, but as shown in this table, cruise above 75% is possible only below approximately 7500'. Military records show that a similar engine to that used in the Cessna 210 on a large light twin lasted 2,000 hours if treated gently (50% power much of the time) vs. only a few hundred hours if pushed hard.

The "max power" available, as pressure drops (altitude increases) from an engine, depending on type of prop., are shown in the 2 columns under the "Max Power" heading. The "constant speed prop" (a misnomer, but beyond the scope of this Aero Nav system, though simple) is shown on the left of these 2 columns, & in the right column, a fixed pitch prop. The columns entitled "Range" give range at the listed power settings, & those in parends indicate the max possible range based on the most economical operating power vs. altitude. Note that a constant speed prop is analogous to an infinitely variable transmission in a car. As the plane climbs & encounters less dense air, the prop “pushes” a smaller mass of air, & thus provides less thrust. Prop pitch is normally flattened for takeoff to allow rpm to increase to increase engine power. It is usually necessary to flatten the pitch at times during climbs for the same reason. But as air thins it is more efficient to increase prop pitch for cruise, again, to increase efficiency. A higher pitch obviously increases the mass of air moved per unit of time. A constant speed prop automatically maintains predetermined power. A fixed pitch prop does not have that luxury, so is normally operating at a compromise; though not seriously. It is not as bad, but similar to a car that has only one forward speed, rather than several. A constant speed prop is even better than a 5 speed transmission, because it is infinitely adjustable; like some small motor scooters. A constant speed prop does provide more control over performance & efficiency, as indicated below.

The optimum prop pitch for any specific atmospheric condition is debatable. During WWII the “experts” were cautious, knowing that too great a pitch subjects the engine to additional stress. High rpm, more than high manifold pressure, causes higher fuel burn. For example, if you downshift your car at cruise, the rpm increases, but manifold pressure decreases. The engine demands less torque, which reduces forces on the bearings, which reduces wear, but the higher rpm increases bearing surface speed, & thus wear. The power required to cruise 70 mph is precisely the same in 4th or 5th gear, in the several bulletproof V-6 Camaros with 5 speed manual transmission that the author has driven since 1984. The C_L is one of the lowest in the industry, which is why several averaged 25 mpg on an 80 mile per day commute, with as much stop & go as on freeways for 25 years. One also averaged 30 mpg using a precise mpg measurement method at a continuous 100 mph for 400 miles up & down mountains on a 2 way test. The fuel burn would be greater in 4th gear, even though the torque is lower, than in 5th gear. A 30 mpg average on long highway trips is the norm; confirmed by other V6 5 speed Camaro owners.

Another major factor in fuel efficiency is “fuel to air ratio”; normally referred to as mixture. The V6 Camaro automatically adjusts fuel flow (injected) so that it runs properly at 11,000’ elevation going up the very steep climb & over Eisenhower peak West of Denver. The Camaro & the author’s son’s turbo Dodge pickup (with a very heavy loaded trailer) had sufficient power to maintain a relatively high speed all the way up. Son’s previous new Toyota pickup with light load required repeated downshift as he crept up the mountain. Thus a trade for a new Dodge was an obvious necessity. Downhill brake quality & safety were an even greater importance. The author’s first plane was a wonderful little 2 place (passenger) all metal Cessna 120 that had no mixture control. As the plane climbed the mixture became progressively richer, & the engine less efficient. The 85 hp Continental engine began to run rough at 10,000’. Some injected aircraft engines, like modern cars utilized automatic mixture control; vs. cars of yesteryear. Some injected aircraft engines utilize manual mixture control. Modern carbureted aircraft engines, though, rely on a manually controlled mixture; sometimes assisted by an EGT (exhaust gas temperature) instrument that improves the ability to more precisely optimize the mixture. The best specific fuel to air ratio is also debatable. Should one lean additionally, or richen it during the leaning (mixture adjusting process), once peak EGT has been achieved? Actually it does depend on the % power; at high power settings it should be richened slightly. At < 65% power, it may be leaned additionally by 50 to 100°F EGT. At > 65% power mixture should be richened by 50 to 100°F.

Both prop pitch & leaning per the “accepted methods” had cost lives of many flight crews during WWII; though no one seemed aware of the fact that fuel consumption could be greatly reduced. Ditching was a frequent occurrence, & a major concern. Charles Lindbergh solved the ditching problem even though others had no idea that it was practical to incorporate his “over square” & leaning experience. He was responsible for saving the lives of many American pilots with the combination of the solution of thee 2 problems.

He settled the optimum fuel to air ratio issue by teaching his aggressive leaning method to significantly extend range. He also proved to them that the engine could be operated “over square”; even though many pilots, even to this day, say it is unsafe. Over Square means that the manifold pressure in inches of mercury could not safely exceed RPM in hundreds. Some “experts” claimed that this would destroy the engine; which would have been true at high power settings. Many courageous American pilots had ditched in the Pacific because they ran out of fuel while returning from long over-water missions.

Lindy spoke to the P-38 pilots & very politely recommended increasing manifold pressure & reducing rpm from 2200 rpm to 1600. The rpm change alone meant an enormous violation of the long standing over square rule. They were very skeptical, until he asked to fly with them & prove his point. He did, & landed with vastly more fuel than the others. They quickly adapted Lindy’s fuel saving advice, & ended the ditching at sea. They reduced their fuel consumption to an unbelievable 50% of prior rate. Of course, exceptionally few pilots in history ever approached Lindy’s skill & knowledge level. His knowledge was also exceptionally broad based, involving diverse scientific & medical ventures.

Because the administration was upset with Lindy they refused to allow him to either re-enter the military, or to continue his wide spread consulting. Critical contractors working on the war effort desperately needed his excellent advice, but were forced to terminate the use of his invaluable services. Henry Ford recognized his undeniable expertise involving aircraft, so was the only one to defy the president & use him to the fullest extent. Mc Arthur, too defied the unpatriotic demands & allowed him to fly 50 missions against the Japs where he had excellent success, including air to air combat. The troublesome Corsair & awesome P-38 were 2 that he flew in combat. Lindy also flew nearly every type of combat aircraft, personally determining the solutions to many serious operational problems. His expertise was finally recognized at the top when he was assigned to a deputation that was sent to Munich to recruit German scientists & fly many German combat aircraft for evaluation purposes.

TAS is a necessary component for Aero Navigation purposes, while IAS must also be known, because that is what the plane responds to in terms of operational speeds, including stall, climb & glide speeds; effective “air speed” over the wing. As air density decreases with altitude, the wing loses lift. Lift must remain at aircraft weight, so since there is a practical limit on how much faster the plane can fly, the angle of attack must be increased to maintain wing lift. Fig F-2 illustrates a typical C_L (Coefficient of lift) vs. Angle of Attack curve. Each airfoil design has a different C_L. This curve shows that an angle of attack of 16° gives the max C_L of nearly 1.72 Max C_L is the point where the C_L begins to decrease, so a much lower C_L would be preferred.

F.d A review of the 1968 Cessna 210 Centurion flight manual shows the following:

A hypothetical trip in the Cessna 210 of Fig F-3 **.** Consider a take-off from Santa Fe, New Mexico, which has an elevation of 6345 ft MSL (vs. usually stated 5,280’ at Denver; & 5,883 for Denver Centennial airport). The Cessna 210 Centurion is an excellent plane for this flight & analysis. It is a very popular high performance plane with a retractable landing gear, & carries 6 passengers. This plane was the fastest, most popular & efficient high performance single engine lightplane for much of its period of manufacture; from 1959 to 1985. Over the years the horsepower, gross weight & seating were increased, from a “limited” 6 place & 3100 lb. in ‘59 to a “true 6 place” & gross weight of 3800 lb. in 1970, & eventually to a 4100 lb. gross. Turbo charged & pressurized versions offered even more impressive performance.

Stall speed is 66 [75] mph IAS with the recommended 20^0 flap setting, at 3400 lb gross weight. The open number represents recommended IAS regardless of field elevation or temperature; the number in the bracket is TAS for the elevation of Santa Fe, at an ambient temp of 80°F, or at other conditions stated below.

The nose gear of a 1968 Cessna 210 should be lifted, in preparation for lift-off, at an Indicated Air Speed of 60 [66] mph, but actual lift-off must exceed the 66 [76] mph IAS stall speed with the recommended 20^0 flap setting, at 3400 lb gross weight.
Initial Indicated Climb Air Speed should be 105 [119] mph, except if a “max performance” take-off is desired to clear obstructions, in which case it should be 70 [79] mph.

After obstacle clearance, “cruise-climb” may be 120 [136] to 140 [159] mph. These cruise climb speeds become 120 [154] to 140 [179] just before leveling off at 15,000’ at -28°F OAT. Level at 15,000’ the 210 may be cruised at anything between 98 [125] at 38% power & 130 [166 mph] at 50% power. The options for climb speed afford a choice of faster climb or covering more ground during a slower, longer climb. The 66 mph stall speed is based on IAS, so the actual speed rolling along the ground at Santa Fe, with no surface wind, would be 75 mph. This disparity gives insight into a concern of pilots operating out of high elevation airports. It obviously takes more power & runway (length) to accelerate to 75 mph, than to 66 mph. Thus a low powered plane may not be capable of taking off from Santa Fe; especially at higher temps. Conversely, max power available is engine ”rated power”, but only at sea level & 59°F. At higher elevations or temperatures the engine produces less power, while the plane requires more power to take-off & to climb. Thus it’s obvious that even a high performance plane will eventually “run out of power” to take off or to climb as elevation or altitude increase. If Santa Fe were to be at a record high temp of possibly 100^0F, the true air speed for lift-off even at stall speed of 66 would be 79 mph vs. 76 at 80^0F; not a major increase, but enough to increase take-off roll from 550’ to 650’ at max gross & 80°F, per the Cessna 210 manual. ROC would be 1350 fpm at standard temp of 36°F & 1200 fpm at 80°F.

Max cruise of this plane is over 190 mph TAS at 10,000’ (max recommended altitude for flying without oxygen). Standard temperature lapse rate for unsaturated air is 5.4^0F / 1,000’, so the temperature would decrease 18°; for a 62°F OAT (outside air temp); or temp of 33^0F at 15,000’. The reported 190 mph true air speed would result from indicated air speeds of 158 or 147 mph respectively. As a matter of interest, this 40 year old plane, properly maintained, as mandated by the FAA, would still be quite a good performer, & essentially as safe as when new. It could fly over 1300 miles on a fuel load. Properly flown by a proficient pilot it would certainly be safer than driving; or for that matter, than boats & trains, per some reported statistics. It is definitely one of the safest high performance lightplanes in the air.

Stepping down somewhat is the Cessna 182, a 4 passenger plane powered by a 230 hp, 470 cu in. 6 cylinder Continental air cooled engine that will typically fly 2,000 hours or more with no failures & very few, if any problems requiring unexpected minor maintenance. The normally aspirated engine powered plane has a 2800 lb max gross weight, 925 to 1200 mile range, 18,900' service ceiling, & cruise speed up to 165 mph TAS.
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Even the low powered Cessna 150 has adequate performance for Santa Fe on a hot day. A "bullet proof" (meaning maintenance free; & safe & reliable) 2 place high wing miniature Cessna 172. Earlier versions powered by 100 hp vs. 145, or in later versions (model 152) 115 & 160 hp. The 172 carries 4 people, is slightly faster on both cruise & stall, & carries much greater payload. The 1964 Cessna 172 had a useful load of 1045 lb, & cruised at 118 to 131 at 65 to 75% power, depending on altitude, & had a range up to 725 miles. Take off roll & distance to clear a 50 ft obstacle at sea level & no helpful headwind is 435 - 780 ft at 1700 lb gross & 865 - 1525 ft at max gross weight of 2300 lb. At Santa Fe, on a standard day, these numbers became 709 - 1260 at 1700 lb & 1455 - 3365 ft at max gross. Not much longer than for the 210. ROC of course, is lower for the; 400 fpm at gross for 172 vs. 1200 fpm for the Cessna 210. The 150 & 172 are powered by a 100 & 145 hp , 200 & 300 cu in. 4 & 6 cylinder (respectively) Continental air cooled engines that will typically fly 2,000 hours or more with no failures & very few, if any problems requiring unexpected maintenance.

APPENDIX G: Regulations

Airspace Regulations That Must be Followed:

Flying has a governing authority; in the case of flying in the U.S., the FAA (Federal Aviation Agency). State & municipalities rarely have any control over any flying activity.

There are a moderate variety of regulations relating to "airspace" which limit or control pilots in how & where they may navigate an airplane. Some basic rules will be briefly discussed here. A pilot must, of course, maintain a specific altitude generally, by use of the altimeter (with reference to the direction of flight, & the Sectional for elevation). An airplane, like a car, requires knowledge of a variety of laws, such as specific street lanes for cars, or altitudes for planes. Each must avoid specified prohibited places. There are standard procedures for entering the traffic pattern of an "uncontrolled" (no control tower) airport. To fly over congested areas, a plane must remain at or above 1,000' above the highest point within a 2,000' radius of its position. The minimum altitude becomes 500' in sparsely populated areas. It is prudent to fly much higher over large cities to increase the availability of suitable emergency landing sites.

Above 3,000' AGL (above ground level) & below 18,000', VFR flight must be flown at odd thousands of ft. plus 500' if heading is between 0 & 179° magnetic course; it must be even thousands plus 500' for 180 – 359° magnetic course. The same directions & altitudes apply to IFR flight except without the 500' adder. If a pilot is flying East under VFR he must fly at 3,500' or 5,500', etc., or 3,000, 5,000, etc for IFR. Westbound; 4,500, 6,500 VFR or 4,000, 6,000, etc for IFR. IFR clearance can be assigned for unusual altitudes by ATC (Air Traffic Control), at their convenience. In the case of IFR, he must fly at or above MEA (Minimum Enroute Altitude), & the MRA (Minimum Reception Altitude) values found on enroute charts. There are also several types of "controlled airspace".

The "Continental Control Area" encompasses all airspace in the lower 48 & Eastern Alaska at or above 14,500' except for airspace less than 1,500' AGL (above ground level); another exception is a restricted area. Positive Control Area includes specified airspace within the U.S. at & above 18,000' MSL to & including FL 600 (60,000'). Transition Area includes airspace from 700 AGL; or lower if specified in conjunction with any airport that has an approved instrument approach, or from 1,200' AGL or higher if designated in conjunction with airway segments. Unless otherwise specified, transition areas terminate at the base of overlying airspace. Transition areas may contain IFR traffic during transition between the IFR route & the terminal area.

APENDIX H: A Typical Flight

Plan a Trip from Houston TX (T41) to Albuquerque International (ABQ)

A hypothetical trip from T41 (on the SE side of Houston) to ABQ requires consideration of distance, route restrictions, winds aloft, flying conditions (VFR or IFR), true courses, headings, navigation-aids, possible fuel stops, restricted airspace, & obviously pilot & aircraft condition.

A pilot, if he as a choice, as if in a large flying club, could choose among several possible designs. Not many clubs would offer all of the below, but most would be offered in a club. The flight could be made in a great little antique, through fast, modern planes:
Slow but practical 95 mph T-Craft BC-12D. Still much faster than by road. Sportplane
Same T-craft with 24 gal fuel & 100 hp engine; 120 mph, 500 mile range Sportplane
Antique Cessna 120, 115 mph
Cessna 150, 120
Cessna 172 (130 mph, 650 mile range)
Similar but poorer performer & much less reliable Piper Cherokee 180 120 mph
Cessna 182 160 mph
Cessna 206 160 mph, 900 range
Cessna 210 190 mph 1200 mile range
Piper Cherokee 6: 160 mph, 800 range
Turbocharged Piper Malibu: 235 mph, 1800 range
Beech (1978 – '82 Duchess: 190 mph, 900 range
Turbocharged Beech Duke: 260 mph, 1,000 range.
Other possibilities include Beech, Cessna or Piper light twins.
Beech King Air is a wonderful turboprop for long trips & a large number of passengers.
Even light biz jets (business jets) that are affordable only by the wealthiest. Cessna Citation is by far the best for short runways, with single pilot approval & exceptionally short field capability.
Gulfstream is probably the best overall for larger loads.

The pilot must be in proper physical condition, & have a current medical, unless he & the plane both qualify for the new sport pilot & LSA (light sport aircraft) rules. If he experiences a temporary medical condition that might impair his flying judgment, ability, or reflexes, he certainly should temporarily ground himself. In sportplanes a prudent pilot would also ground himself if not fully safe to fly. He should be "current" as defined by the FAA; recent landings, night (though night flying is not quite as safe as daytime, & he will have only about 10% of the airports available for use), etc. If IFR rated, & IFR conditions are possible, he should be "current" in IFR flying. The FAA rules do change occasionally for both, but IFR requires a few instrument approaches within the past 90 days.

If renting a plane he must obviously be checked out in the plane he plans to fly, but more important than that, he should be competent, confident, & comfortable for all aspects of flying the plane, as well as for the flight anticipated. He should be well aware of the nuances of mountain flying since he will be flying over some very high elevation level ground, as well as mountainous terrain. Mountain flying does have some distinct differences that must be understood. Another issue; some low performance planes actually could not operate off of the high elevation field at ABQ on a hot day. The ever popular Cessna 150 & 172 are safe, in skilled hands, operating out of 9,000' elevation airports. Cessna 182 & 210 even better.

Conversely the author tried to rent a Piper Tripacer (similar to the Cessna 172) for a trip from central Mo to Albuquerque. The FBO refused because of poor Tripacer high altitude performance. Pilot qualifications were not an issue, since the FBO had just offered the 18 year old author a job as a crop duster; College interfered, so it did not materialize).

He should verify operational avionics, &, via FSS contact, NOTAMS (for possible inoperative navigation aids or airport systems). He should obtain enroute weather & winds aloft & on the surface from FSS (though it is now available on the internet). Note that ABQ has been known to have some severe winds at times. Severe winds can be even more of a hazard to flying in mountainous terrain than during T.O. (take-off) or landing because of the potential for extreme up & down drafts.

"Mandatory" current Sectional charts for this flight include Houston, San Antonio, Dallas-Fort Worth, & Albuquerque. It would be wise to also carry an El Paso chart in case of major detours for unexpected weather systems. Sectional charts are described in detail in the Map Reading Aero Nav system in this series. Sectional charts, which expire every 6 months, cost $0.25 when the author began flying age 16. The price slowly crept up to $8.00. If IFR conditions are "possible" (IFR charts are not as readily available at FBOs as Sectionals), current enroute charts & approach plates are mandatory. Both are much less expensive than Sectionals. The Enroutes required are L-17, L-15, L-13, & L-4 (listed in the order to be used on a flight from T-41 to ABQ) are $4.10 each. Approach plates are $4.25 each. They expire every 56 days, & contain very few terrain features. They do include extensive airway info, including airway identification number & magnetic course between adjacent VORs (for OMNI), MOCA (min. obstruction clearance altitude), MEA (min. enroute altitude), MCA (min. crossing altitude), MRA (min. reception altitude), MEA for GPS Navigation, a variety of pertinent distances, & intersections. Approach plates are indexed by airport, & sub-indexed by type of approach. They also expire in 56 days, but for his flight only 4 sets of approach plates are required; SC-5, SC-2, SC-3, & SW-1. Texas is the only state that has so many IFR equipped airports that 3 sets of approach plates are required. Calif. has 2, & most states share their approach plates with 1 or more other states. TX has 7.7% (Calif. has 6%) of the pages in the "best" airport directory available; even used by the FAA in its FSS & other facilities. It was published annually by the AOPA (Aircraft Owners & Pilot's Assn) until they changed from paper to "on line". The break-down is based solely on the thickness of a set of approach plates. Enroute charts & approach plates are described in detail in the Instrument Approach system in this aero Navigation series.

The above listed Sectional charts should be spread out on an uncarpeted floor to properly plan a simple (no GPS or LORAN) VFR flight, if it is desired to find an option. The excellent flight planning capability of the Aero GPS such as the most popular (Garmin) moving map hand held GPS can be used to preflight a great circle route, & then broken down into shorter segments for transfer to the Sectionals. One excellent option is to establish the route with one of the above methods one time, & document a route at crossing points along the edges of each of the charts. Subsequent charts can simply be drawn by copying these critical end points. The GPS system in this aero navigation series provides great detail on its capability. It seems to have unending capability. It is actually practical (certainly not legal) to fly VFR with no charts at all with a good GPS; IF it NEVER fails. Many pilots no longer draw intended course & mark incremental distances along it, in view of the convenience of the GPS, but it is prudent to have clearly marked charts in case of GPS failure. Nor are OMNI flights without marked up Sectionals recommended. The very useful NOAA (the Federal Chart Making Service) "Flight Case Planning Chart" covers the entire U.S. on some large sheet. It is intermittently published, so a good idea is to buy an extra one for safe keeping, since they do wear quickly, if carried in the flight kit. It is definitely not adequate for actual navigation. It includes VORs & airways as well as airports. It even has a handy mileage table for distances between a few of the 16,000 airports in the U.S. This mileage chart shows the direct route between HOU (Hobby Airport) & ABQ to be 660 nautical miles. The distance between T41 & HOU is approximately 10 NM, so the distance becomes 670 NM. Since winds are given in knots instead of mph, it is more convenient to preflight (plan) & fly using nautical miles.

The flight is 670 nautical miles, with a magnetic course (average) of 290° for the flight from HOU to ABQ.

For a specific January, '09 day, the winds were reported per the below. Note that some reporting stations do not list lower level winds. That's because field elevation exceeds or closely approaches some standard reporting levels. ABQ elevation is 5352' MSL (mean sea level). Abilene is 1,790', but close enough to 3,000' that winds aloft are not reported for this level.

Surface winds & winds aloft were as follows:

Fig H-1

Airport	Winds	Winds Aloft					
	Surface	3,000'	6,000'	9,000'	12,000'	(15,000')	18,000'
HOB	260/10	200/13	190/10	290/10	260/12	(280/14)	300/16
ABI	230/11		220/17	230/17	250/16	(270/15)	290/14
ABQ	270/5			290/16	300/25	(310/30)	320/35

In view of the severely unfavorable winds, & the ability to cruise as high as 20,000' in this 182, & the fact that oxygen is available, the pilot may elect to make an intelligent guess, & interpolate for 15,000' winds; based on the trends he saw. Those "guesses" are shown in parends.

He would usually just browse the winds & make a judgment on a good altitude, but with such unfavorable winds, & the fact that relative impact are not inherently obvious, he should compute several wind vectors on his E-6B. There is no need to compute wind vectors for all altitudes, but it is important for those with subtle differences. He will also want to avoid major altitude changes enroute without a measurable benefit.

Surface winds are negligible since a climb will place the plane under influence of higher elevation winds very quickly. The 182 climbs at, or greater than 1,000 fpm (ft per min) at SL, & even at 10,000' (where power is lower & air is less dense) it climbs at over 500 fpm. In this case winds tend to be very unfavorable, so if the pilot has a choice of several planes, as he might in a flying club or rental, he may wish to select a rather fast plane, as long as he is proficient, qualified & comfortable flying it. He may prefer a Cessna 182, which is faster than the old faithful Cessna 150 or 172 that he may be more comfortable with, & more stable, with faster cruise climb, as well as carrying a heavier load than a similar Piper. The 182 also performs considerably better than similar Pipers at higher elevations. The high performance Cessna 210 is not often available to renters, so he may never have "checked out" in it. Or he may not be current (specified number of recent landings, etc) in it, if his club has one. All 4 carry quite a payload, but after selecting a 1968 Cessna 182, he sees in the manual the following:

Range is the 1st question for such a long flight. The 182 was sold with either 60 or 79 gallon tankage. Fortunately most have 79 gal tanks, & in the interest of engine life & fuel cost, he selects a 65% cruise. The plastic flight computer permits determining intermediate power settings, or exactly 65%, but looking at the manual he sees the below:

Fig H-2

Altitude	Cruise Speed (TAS)	Range
2500'	129 kts (149 mph)	845 N.M. (970 stat mi) at 2300 rpm, 67% power, & 22"Hg M.P. or
2500'	131 (151)	820 N.M. (940 stat mi) at 2450 rpm, 68%, & 21" Hg M.P.
5,000'	135 (155)	840 (965) 2300 69% 22" Hg M.P.
7,500	136 (156)	877 (1005) 2300 66% 21" Hg M.P.
10,000	132 (152)	943 (1080) 2300 60% 19"Hg M.P.
15,000'	124 (143)	1021 (1170) 2300 50% 16"Hg M.P.
20,000'	110 (126)	1039 (1190) 2300 42% 13"Hg M.P.

HOU winds & Influence on the flight:
2,500' 129 kt TAS with 200/13 winds gives 128 GS with 6° right drift.
4,500' 131 kt TAS with 195/11 winds gives 130 GS with 5° right drift; at higher altitudes the headwind component is quite large.

ABI winds & Influence on the flight:
4,500' 132 kt TAS with 220/17 winds gives 126 GS with 7° right drift.
6,500' 134 kt TAS with 220/10 winds gives 127 GS with 7° right drift.
8,500' 135 kt TAS with 230/17 winds gives 126 GS with 6° right drift.
10,500' 135 kt TAS with 240/16 winds gives 124 GS with 4° right drift.
12,500' 133 kt TAS with 250/16 winds gives 119 GS with 4° right drift.
14,500 130 kt TAS with 270/15 winds gives 116 GS with 2° right drift.

ABQ Winds & Influence on the flight:

8,500' 135 kt TAS with 290/16 winds gives 119 GS with 0° drift (on nose).
10,500' 135 kt TAS with 295/20 winds gives 115 GS with 1° left drift.
12,500' 133 kt TAS with 300/25 winds gives 108 GS with 1° left drift.
14,500' 130 kt TAS with 310/30 winds gives 102 GS with 5° left drift.

He should steer to a point 40 miles South of ABQ to permit a more gradual descent into ABQ, since a steep descent after crossing the higher mountains just East of ABQ is not as efficient, & it is hard on the engine to cool cylinders rapidly by making a rapid descent. He should plan on crossing the mountains near ABQ while cruising at 12,500, if not at 14,500'. This, then, should be his preferred altitude range for the last half of the flight. By taking a "Dog Leg" to the South his MEA from Corona VOR to the intersection named Budpy is only 9700'.
Had he proceeded directly from Corona to ABQ the MEA would have been 12,000', & even then he'd have made a small heading deviation at Cabus intersection.

First he needs to compare wind components in terms of angle off nose. An initial magnetic course of 290° suggests an initial cruising level at 2,500' [close to 3,000', but altered per the heading vs. altitude rule; if cruising above the 2,500' AGL (above ground level)] for the 1st few hundred miles might be preferred. His E-6B or equivalent flight computer indicates the following for the entire route & several altitudes:

Suggested altitudes based on the above:

4,500' from HOU to ABI (297 NM) at 131 GS, then up to 6,500 toward Lubbock (128 NM) at 127 GS, & within 25 NM, start climb to 10,500', & cruise at 115 GS until across mountains 40 NM South of ABQ (245 to ABQ).

Total time roughly 5-1 / 2 hours. Vs. at least 15 hours driving with mostly 75 to 80 mph speed limit.

Quite complicated, but justified to optimize GS vs. terrain clearance. More casual flight planning (or none) on a flight like this 1 could easily cost the pilot half an hour; or even more.

What would be the best altitude for the return flight if winds remain as above. Stay high for better winds for the most part; 15,500' averaging roughly 170 kts GS for nearly 4 hours.

The differences in speed & range prove again that lower rpm & higher M.P. (manifold pressure) are more efficient than the converse, as well as reducing engine wear.

Note that speed in mph (statute) is 15% larger than in kts (given above). So the above flight would be made at speeds up to 156 mph.

Based on the Cessna 182 manual data, & the above assumptions, the pilot can expect to cruise at 131 kts at 2500' for the first 1/3 of the flight, & 135 kts for the second 1/3 rd of the flight at 6,500' & 127 kts for the last 2 / 3 of the flight at 12,500'. Once into the airspace (above 1,200' AGL) the altitude must be "odd plus 500' "; thus 5,500 & 13,500'.

APPENDIX Ⅰ: Dream Plane

Ⅰ.a Dream Plane for a Family of 6:

Fig Ⅰ - 1: Author's Cessna (paint design by his artist-pilot-wife)

Fig Ⅰ - 2: Author's Exceptionally Well Equipped, IFR Certified Instrument Panel

The family Cessna was an amazing & wonderful, safe, "bullet-proof" plane that added tremendously to quality of life of the author's entire family. Their 3 sons & daughter still frequently thank them for that wise choice; for broadening their experiences & knowledge of geography, history, & appreciation of the beauty of this great country, & beyond.

The third (first new; shopping for 4th at time of writing) plane bought by the author & his wife; & flown for 41 years. An informal equipment list is included. All avionics are described starting above the panel, & then at top left of the "flight panel" (left side for flight instruments), & working down; & then the radio stack, & then the "engine or power panel at the far right.. This aircraft had an exceptionally large compliment of avionics after many upgrades. This was simply the result of 2 serious pilots & an engineer's "desire" for all possible "gadgets" & in-flight information.

AVIONICS SUMMARY: 35 instruments, 4 Transmitters, & 11 Receivers including 2 integral computers, & Dual Collins Microline Navcoms

Ⅰ• b Instrument Panel & Equipment List for Author's Well Equipped Cessna

The instruments shown are described from the top down, & left to right, including "out of view items", & below the instrument panel eyebrow, by panel type. First "Flight Panel" at left side; then "Radio Stack area"; then the "Engine Panel" at right the side; & then below the panel.

Above Instrument Panel Eyebrow:

OAT out of sight
Magnetic compass
Collision avoidance receiver

Flight panel:

Auxiliary digital oil temp gage; top right of flight panel.
Loran CDI (Course Deviation Indicator) for IFR
Air Speed Indicator calibrated in MPH & Knots.
Attitude gyro; vacuum powered
Altimeter; 3 needle sensitive type.
OMNI no. 1 needle CDI with glide slope
Directional gyro; vacuum powered.
Remote compass; a superb instrument.
Aileron trim rocker switch (on wheel)
Boom microphone switch on pilot control wheel
Switch is on right hand control wheel.
Aileron trim is uncommon for lightplanes).
Mini vacuum gage to monitors AG & DG
Rate of climb.
OMNI no. 2 CDI; vertical needle
Turn & bank indicator; "primary panel"
Aux tank fuel gage
Oxygen flow control valves for > 10,00'
Aileron trim indicator

Control Wheel:
Pilot's control wheel:
Com transmitter microphone key switch
Aileron trim rocker switch
Co-Pilot's control wheel:
Com transmitter microphone key switch

Radio stack section:
Digital oil temp gage
2 oxygen flow Rotameters
Audio panel selector switches.
Altitude nag.
Collins Transponder
Foster Loran; replaced a DCE
Collins Com No.1 720 Channel Transceiver.
Collins Navigation No.1 receiver
Collins Com No. 2 Transceiver
Garmin GPS with Moving Map
Collins Navigation No.2 receiver
Custom "center normal" aux gas pump ampmeter
ELT mini control panel; Switch
Aileron trim position indicator

Power panel:
Tachometer
Manifold Pressure gage Ammeter.
Left fuel gage.
Oil pressure.
Oil temperature.
Right fuel gage.
Carb air temp gage;
Exhaust temp gage optimizes leaning
Narco ADF with integral marker beacon receiver.

Ancillary Devices:
Collins glide slope receiver is under the right seat.
ELT (emergency locator transmitter) in tail cone.
Remote compass sensor / sender in tail cone.
Extended baggage compartment.

CONTROLS:
Audio Panel
Aux Fuel Tank Pump Switch

Radio master switch.

Boom Microphone Microswitches

Master & magnetic Switch, Circuit Breaker Panel

Electric Aileron Trim Switches (2)

Pitot heater switch

Elevator Trim Indicator/Control

Dual Brakes (& Controls; nominally an option)

Vernier mixture control

Aileron trim control switches (2)

APPENDIX J: Puzzlers

Puzzler No. 1:

Greatest Navigation Mystery & Accomplishment in History; the Homing Pigeon

The author has used many types of navigation, & has a reasonably good understanding of the few that he has not used. He is, however, totally baffled by the homing pigeon; as is the entire world of science. A broad series of studies by many scientists have resulted in only about 3 possibilities, but all except 1 of these are flawed, & the best only solves part of the puzzle.

Put the author in the trunk of a car, & drive him any direction you choose, for any distance imaginable, & ask him where he is. He will not have a clue !!!

Give him a compass, & repeat the experiment, & the result will be very little better; only, possibly, that the entire time was spent heading North.

Give him a map, compass, & watch, & allow him to guess by sound & severity of bumps how fast he was traveling, & he will still have only a vague idea.

But the pigeon goes to the exact spot (home); from 1,000 miles away.

The technology of any form of navigation that could help a person identify the destination would be less than 100 years old, unless at night with celestial capability. Celestial is only useful in finding a "fix" if the navigator has star charts & tables & a very exact time piece. The only definitive explanation for any part of the homing pigeon's amazing ability is when a magnet secured under 1 wing did confuse them. But a compass alone would not be adequate.

Does anyone think a pigeon could have evolved, not only to come into existence, but to have the inherent ability to use a form of navigation that modern science can neither explain nor duplicate? Statisticians do not. In fact, they can explain why the pigeon could not have evolved with this fantastic capability. They say the chances of the pigeon evolving with this capability is less than 1 in 10^{350}. They call it the Burrell number. The Burrell number states that if something has less than 1 chance in 10^{150} of occurring, it is indeed impossible. Though the readers are quite familiar with exponents, & the enormous magnetic of even small exponents, a comparison may be helpful. Those same statisticians say that there are only 10^{9} atoms in the Universe. Mind boggling. So how can the pigeon do the impossible? Could it be that there is indeed a Creator?

Puzzler No. 2:

An airplane prop can windmill (continue to rotate under relative wind forces) after an engine loses power in flight. If so, the drag area is that of a flat plate of the same diameter. If the pilot slows the plane enough that the prop stops it will only have a drag area of the blade width x length. A drag area reduction of > 15.

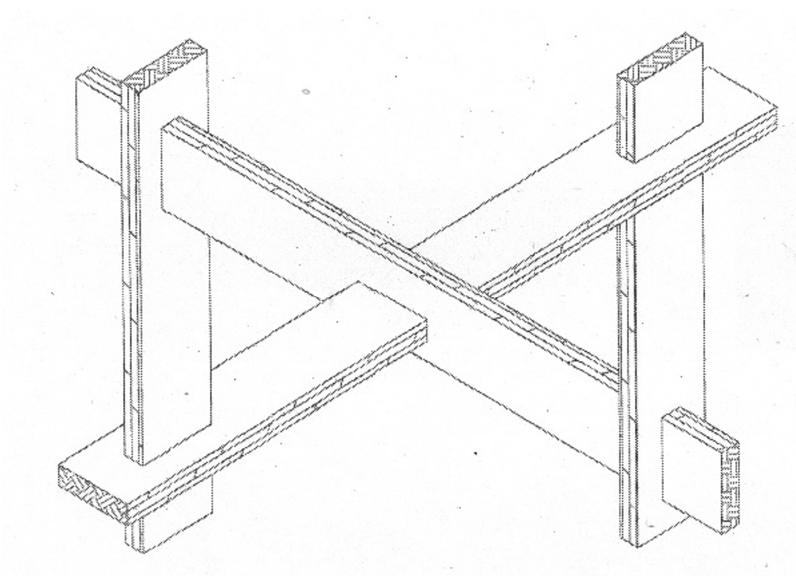
Puzzler No. 3:

A pilot can deceive a passenger into thinking they are in a steep left bank (turn) while actually being in a steep right bank.

A "trick" the author pulled on students pilots to quickly convince them of the importance of trusting their instruments worked very well. He asked them to put the IFR practice (or training) hood on, & look down. He then began lowering one wing very slowly. As the bank reached a point so steep that the plane was nearly ready to "fall off on a wing", he quickly applied opposite aileron; but only rolled out until that wing was still 30° wing low. Then he asked student to look up & at instruments & return to level flight. All were puzzled because the instruments showed the high wing was in fact low. It took will power to respond correctly, because after that rapid rolling action, his senses "had to be right". A person can actually be inverted & think he is right side up. Aerobatics can also confuse a person. A solution to that is to keep eyes on the horizon; even if it vanishes as in entering a loop; then look to the side.

Puzzler No. 4:

Compute the weight of the popsicle stick "trinket", & then make one & weigh it.



Puzzler No. 4:

APPENDIX K: References & Credits for Illustrations

Credits for Illustrations:

Most illustrations were taken from the public domain; US Government publications & assorted Aero Navigation books on which copyrights had expired, or cases where publishers are no longer in business.
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A few were taken from public domain Internet releases.

Fig 14; "Wake Turbulence" on. Taken from the author's copy of Dr. Irvin Gleim's excellent Private Pilot Handbook (3 rd edition (1990); page 58. Reproduced with permission from Gleim Publications Inc., www.glein.com, Pilot Handbook by Gleim Publications Inc.

The 9 th edition, copyright © 2009, is greatly improved. Several were created by the author using ACAD or other means.

Several were created by the author from items that he digitally photographed or scanned on one of his HP flat bed scanners (necessary since other scanners do not have adequate 3-D capability).