PDHonline Course R143 (3 PDH)

Engineering Ethics Case Study: The Challenger Disaster

Instructor: Mark P. Rossow, Ph.D, PE Retired

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

The Challenger Disaster and Engineering Ethics

Mark P. Rossow PE, PhD
Emeritus Professor of Civil Engineering
Southern Illinois University Edwardsville

Also published as *The Challenger Disaster and Engineering Ethics – Kindle Edition*

The cover image is part of the collection: NASA Images. From the description given on the website:

> "Close-up view of the liftoff of the Shuttle Challenger on mission STS-51L taken from camera site 39B-2/T3. From this camera position, a cloud of grey-brown smoke can be seen on the right side of the Solid Rocket Booster (SRB) on a line directly across from the letter "U" in United States. This was the first visible sign that an SRB joint breach may have occurred. On January 28, 1986 frigid overnight temperatures caused normally pliable rubber O-ring seals and putty that are designed to seal and establish joint integrity between the Solid Rocket Booster (SRB) joint segments, to become hard and non-flexible. At the instant of SRB ignition, tremendous stresses and pressures occur within the SRB casing and especially at the joint attachment points. The failure of the O-rings and putty to "seat" properly at motor ignition, caused hot exhaust gases to blow by the seals and putty. During Challenger's ascent, this hot gas "blow by" ultimately cut a swath completely through the steel booster casing; and like a welder's torch, began cutting into the External Tank (ET). It is believed that the ET was compromised in several locations starting in the aft at the initial point where SRB joint failure occurred. The ET hydrogen tank is believed to have been breached first, with continuous rapid incremental failure of both the ET and SRB. A chain reaction of events occurring in milliseconds culminated in a massive explosion. The orbiter Challenger was instantly ejected by the blast and went askew into the supersonic air flow. These aerodynamic forces caused structural shattering and complete destruction of the orbiter. Though it was concluded that the G-forces experienced during orbiter ejection and break-up were survivable, impact with the ocean surface was not. Tragically, all seven crewmembers perished."

Preface

This book presents an explanation for the Space Shuttle Challenger disaster that differs significantly from conventional explanations. The book is intended for three audiences: 1) students in engineering ethics classes, 2) practicing engineers concerned about professional ethics issues, and 3) laypersons interested in gaining a more accurate picture of one of the most publicized and misunderstood technological disasters of the twentieth century.

After the disaster occurred, a presidential commission investigated the causes and produced a report, *Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident*[1], which was very influential in creating the conventional explanation of the disaster. Much more complete accounts of events leading up to the disaster were given in books by the sociologist, Diane Vaughan, in *The Challenger Launch Decision*[2], and by the historians, Andrew Dunar and Stephen Waring, in *Power To Explore -- History of Marshall Space Flight Center 1960-1990*[3]. As Dunar and Waring put it—and their remarks apply to Vaughan's work as well—"Allowing Marshall engineers and managers to tell their story, based on pre-accident documents and on post-accident testimony and interviews, leads to a more realistic account of the events leading up to the accident than that found in the previous studies."

I would strongly encourage anyone with the time and interest to read both of these books, which are outstanding works of scholarship (Besides conducting her own interviews, Vaughan made use of transcripts from 160 interviews—more than 9,000 pages—conducted by government investigators[4]). For those persons lacking the time—the Vaughan book is over 550 pages—I have written the present condensed description of the Challenger incident. I have drawn the material for Sections 1-8, 10 and 13 from multiple sources but primarily from Vaughan, the *Report to the President*, and Dunar and Waring. Of course, any errors introduced during the process of fitting their descriptions and ideas into my narrative are mine and not the fault of these authors. Sections 9, 11, and 12 are original contributions of my own. All figures have been taken from *Report to the President*.

I would like to thank Molly Rossow for reviewing an early draft of the text and suggesting improvements.

Mark P. Rossow

Contents

Introduction

On January 28, 1986, the NASA Space Shuttle Challenger burst into a ball of flame 73 seconds after take-off, leading to the death of all seven people on board. Some months later, a commission appointed by the President to investigate the disaster declared, in the *Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident,*[1] that the cause was the failure of a seal in one of the solid rocket boosters[5]. The commission also said that even though the seals had been recognized as a potential hazard for several years prior to the disaster, management had failed to fix the problem because of a lack of communication between engineers and management and because of poor management practices. Furthermore, the news came out that Morton Thiokol, the contractor responsible for the seal design, had initiated a teleconference with NASA on the evening before the launch and had, at the beginning of the teleconference, recommended against launching because of concerns about the seal. This recommendation was then reversed during the teleconference, with fatal consequences. The commission and many other commentators used the reversal of the recommendation to support accusations of managerial wrongdoing. These observations and accusations taken together became the standard interpretation of the cause of the Challenger disaster. This interpretation routinely appears in popular articles and books about engineering, management, and ethical issues when Challenger is cited as a case study.

But the interpretation ignores much of the history of how NASA and the contractor's engineers had actually recognized and dealt with the seal problems in advance of the disaster. When this history is considered in more detail, the conclusions of the *Report to the President* become far less convincing.

This book begins by presenting the minimum technical details needed to understand the physical cause of the Shuttle failure. The failure itself is illustrated through NASA photographs. Next the decision-making process—especially the discussions occurring during the teleconference held on the evening before the launch—is described. Direct quotations from engineers interviewed after the disaster are used to illustrate the ambiguities of the data and the pressures that the decision-makers faced in the period preceding the launch. The book ends by presenting six ethical issues raised by Challenger. A primary goal of the book is to demonstrate that issues that had appeared simple initially are actually far more complex; pinpointing responsibility and assigning blame are not nearly as easy as many popular accounts have made them.

1. Two Common Errors of Interpretation

Persons studying the history of an engineering disaster must be alert to the danger of committing one of the following common errors: 1) the myth of perfect engineering practice, and 2) the retrospective fallacy.

<u>The Myth of Perfect Engineering Practice</u>

The sociologist, Diane Vaughan, who has written one of the most thorough books on Challenger, has pointed out that the mere act of investigating an accident can cause us to view, as ominous, facts and events that we otherwise would consider normal: "When technical systems fail, … outside investigators consistently find an engineering world characterized by ambiguity, disagreement, deviation from design specifications and operating standards, and ad hoc rule making. This messy situation, when revealed to the public, automatically becomes an explanation for the failure, for after all, the engineers and managers did not follow the rules. … [On the other hand,] the engineering process behind a 'nonaccident' is never publicly examined. If nonaccidents were investigated, the public would discover that the messy interior of engineering practice, which after an accident investigation looks like 'an accident waiting to happen,' is nothing more or less than 'normal technology.'"[6] Thus as you read the description of the Challenger disaster on the pages to follow, keep in mind that just because some of the engineering practices described are not neat and tidy processes in which consensus is always achieved and decisions are always based on undisputed and unambiguous data, that fact alone may not explain the disaster; such practices may simply be part of normal technology—that usually results in a nonaccident.

<u>The Retrospective Fallacy</u>

Engineering projects sometimes fail. If the failure involves enough money or injuries to innocent people, then investigators may be brought in to determine the causes of the failure and identify wrongdoers. The investigators then weave a story explaining how decision-makers failed to assess risks properly, failed to heed warning signs, used out-of-date information, ignored quality-control, took large risks for personal gain, etc. But there is a danger here: the story is constructed by selectively focusing on those events that are known to be important in retrospect, that is, *after* the failure has occurred and observers look back at them. At the time that the engineers were working on the project, these events may not have stood out from dozens or even hundreds of other events. "Important" events do not come labeled "PARTICULARLY IMPORTANT: PAY ATTENTION"; they may appear important only in retrospect. To the extent that we retrospectively identify events as particularly important—even though they may not have been thought particularly important by diligent and competent people working at the time—we are committing the "retrospective fallacy."[7]

In any discussion of the Challenger disaster, the tendency to commit the retrospective fallacy exists, because we all know the horrendous results of the decisions that were made—and our first reaction is to say, "How could they have ignored this?" or, "Why didn't they study that more carefully?" But to understand what happened, it is crucial to put yourself in the place of the engineers and to focus on what they knew and what they thought to be important *at the time*. For example, NASA classified 745 components on the Shuttle as "Criticality 1", meaning failure of the component would cause the loss of the crew, mission, and vehicle[8]. With the advantage of hindsight, we now know that the engineers made a tragic error in judging the possibility of failure of *a particular one* of those 745 components—the seals—an "acceptable risk." But at the time, another issue—problems with the Shuttle main engines—attracted more concern[9]. Similarly, probably most of the decisions made by the Shuttle engineers and managers were influenced to some extent by considerations of cost. As a result, *after* the disaster it was a straightforward matter to pick out specific decisions and claim that the decision-makers had sacrificed safety for budgetary reasons. But hindsight was not available to the people involved in the Challenger project, and as we read the history we should continually ask questions such as "What did they know at the time?," "Is it reasonable to expect that they should have seen the significance of this or that fact?," and "If I were in their position and knew only what they knew, what would I have done?"

2. Configuration of Shuttle

NASA had enjoyed widespread public support and generous funding for the Apollo program to put a man on the moon. But as Apollo neared completion and concerns about the cost of the Vietnam War arose, continued congressional appropriations for NASA were in jeopardy. A new mission for NASA was needed, and so the Space Shuttle program was proposed. The idea was to development an inexpensive (compared to Apollo) system for placing human beings and hardware in orbit. The expected users of the system would be commercial and academic experimenters, the military, and NASA itself. On January 5, 1972, President Nixon announced the government's approval of the Shuttle program.

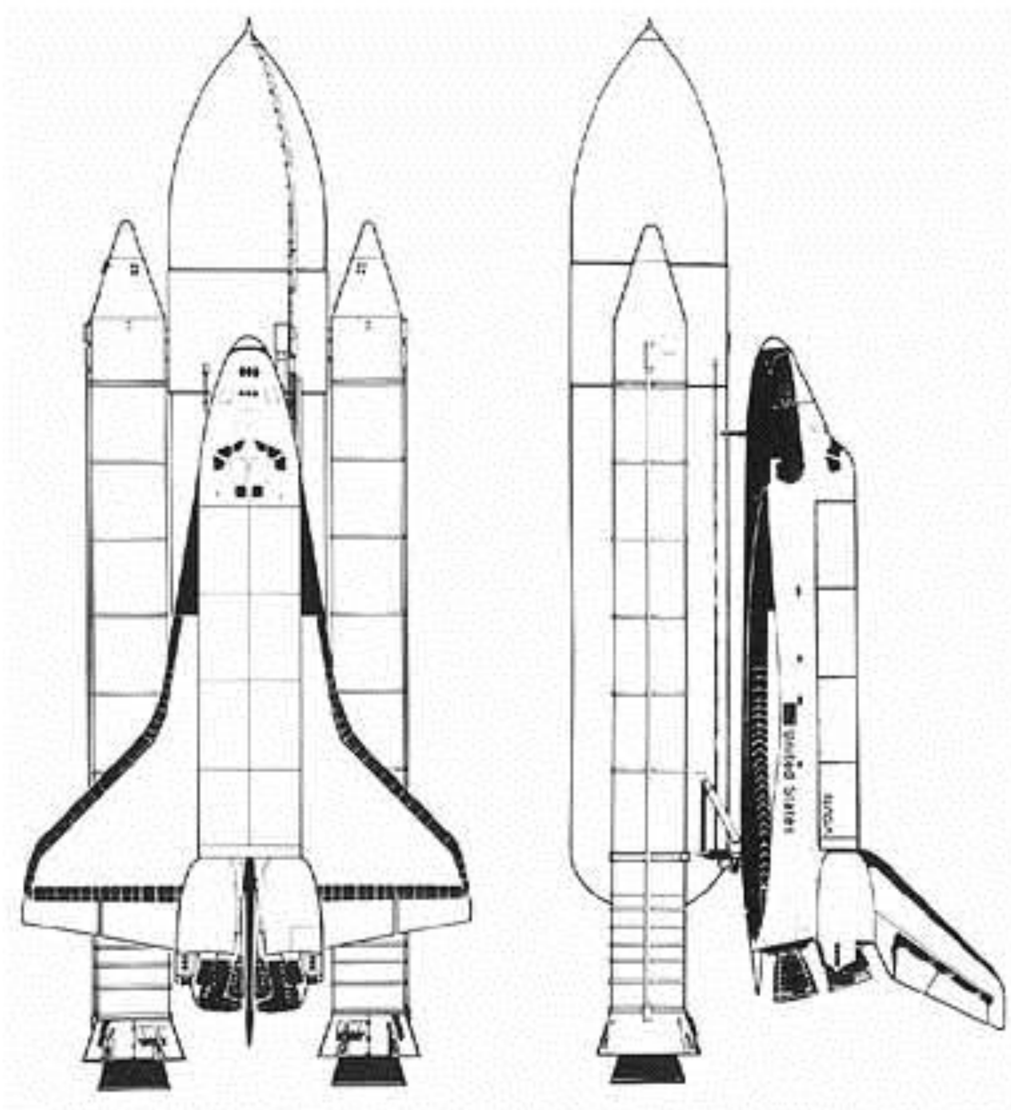


Fig. 1 Configuration of the Shuttle

Because a prime goal was to keep costs down, reusable space vehicles were to be developed. After many design proposals and compromises—for example, the Air Force consented to give up development of any competing launch vehicles, provided that the Shuttle was designed to accommodate Air Force needs—NASA came up with the piggyback design shown in Figure 1. The airplane-like craft (with the tail fin) shown in side view on the right side of the figure is the "Orbiter." The Orbiter contains the flight crew and a 60 feet long and 15 feet wide payload bay designed to hold cargo such as communications satellites to be launched into orbit, an autonomous Spacelab to be used for experiments in space, or satellites already orbiting that have been retrieved for repairs.

Before launch, the Orbiter is attached to the large (154 feet long and 27 1/2 feet in diameter) External Tank—the middle cylinder with the sharp-pointed end shown in the figure; the External

Tank contains 143,000 gallons of liquid oxygen and 383,000 gallons of liquid hydrogen for the Orbiter's engines.

The two smaller cylinders on the sides of the External Tank are the Solid Rocket Boosters (SRBs). The SRBs play a key role in the Challenger accident and accordingly will be described here in some detail.

The SRBs contain solid fuel, rather than the liquid fuel contained by the External Tank.

The SRBs provide about 80 percent of the total thrust at liftoff; the remainder of the thrust is provided by the Orbiter's three main engines. Morton-Thiokol Inc. held the contract for the development of the SRBs.

The SRBs fire for about two minutes after liftoff, and then, their fuel exhausted, are separated from the External Tank. A key goal of the Shuttle design was to save costs by re-using the SRBs and the Orbiter. The conical ends of the SRBs contain parachutes that are deployed, after the SRBs have been separated from the External Tank, and allow the SRBs to descend slowly to the ocean below. The SRBs are then picked out of the water by recovery ships and taken to repair facilities, where preparations are made for the next flight. After the SRBs are detached, the Orbiter’s main engines continue firing until it achieves low earth orbit. Then the External Tank is jettisoned towards earth where it burns up in the atmosphere—the External Tank is not re-used. Once the crew has completed its mission in orbit, the Orbiter returns to earth where it glides (No propulsion is used.) to a landing on a conventional airstrip. The Orbiter can then be refurbished for its next launch.

<u>More Details about the SRBs</u>

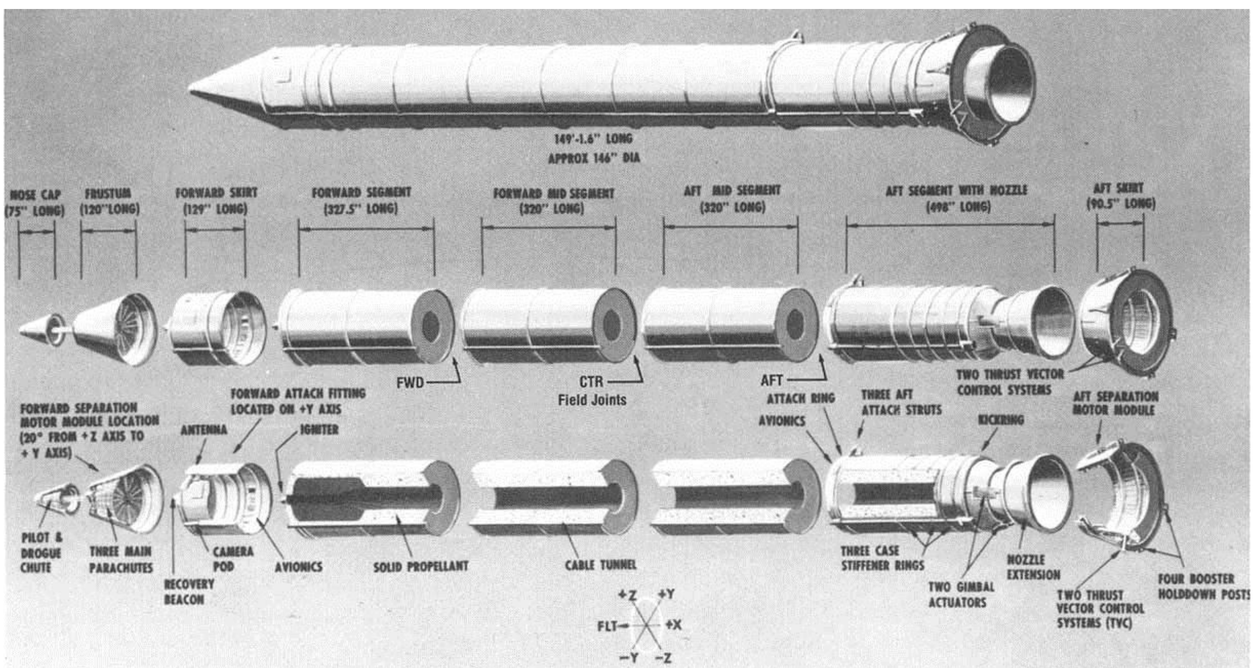


Fig. 2 Solid Rocket Booster with Exploded View Showing Segments and Joints

Figure 2 shows the subassemblies that make up the SRB. Because the total length of the SRB was almost 150 feet, it was too large to ship as a single unit by rail from Thiokol's manufacturing facility in Utah to the Kennedy Space Center launch site in Florida. Furthermore, shipping the SRB as a single unit would mean that a large amount of rocket fuel would be concentrated in a single container—creating the potential for an enormous explosion. For these reasons, Thiokol manufactured the SRB from individual cylindrical segments each approximately 12 feet in diameter. At Thiokol's plant in Utah, individual segments were welded together to form four "casting" segments, into which propellant was poured (cast). The welded joints within a casting segment were called "factory joints." The four casting segments were then shipped individually by rail to Kennedy, where they were assembled—by stacking, not welding—to form the solid rocket motor (SRM) of the SRB. The joints created by the assembly process at Kennedy were called "field joints." The sealing problem that led to the Challenger's destruction occurred in the field joint at the right end of the AFT MID SEGMENT in Figure 2. Hot combustion gases from the SRM leaked through the joint and either weakened or burned a hole in the External Tank, igniting the contents of the Tank and producing a catastrophic fireball.

3. Function of O-rings

The cutaway view of the SRB in Figure 3 shows the aft field joint location in the assembled SRB.

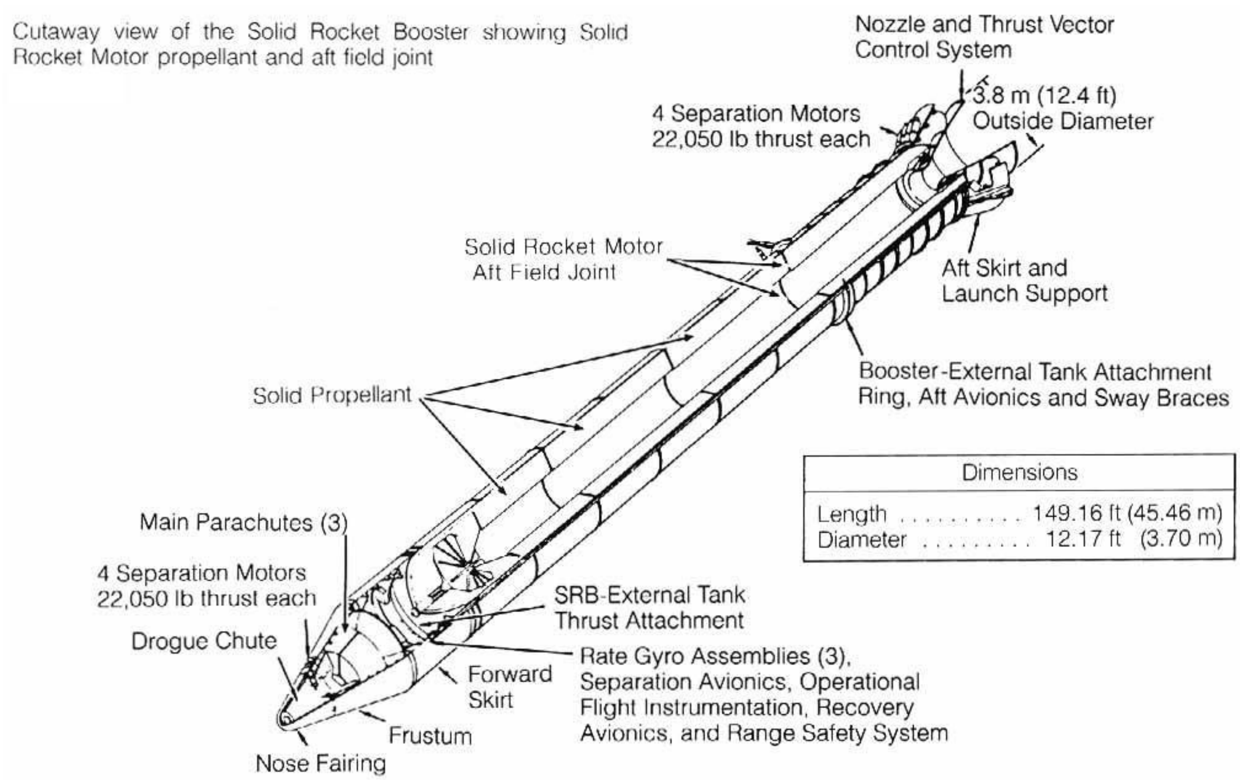
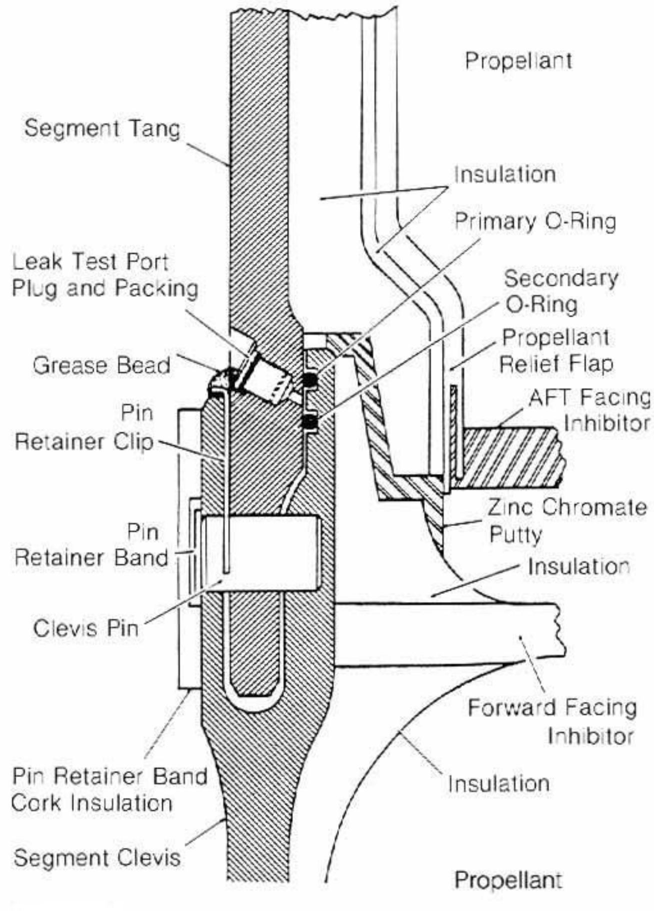


Fig. 3. Location of the Problematic Aft Field Joint



Solid Rocket Motor cross section shows positions of tang, clevis and O-rings. Putty lines the joint on the side toward the propellant.

Fig. 4. Cross Section of Field Joint

Figure 4 shows how the upper SRM segment in a field joint is connected to the lower segment by a pin passing through the "tang" (the tongue on the upper segment) and the "clevis" (the U-shaped receptacle cut in the lower segment); 177 such steel pins are inserted around the circumference of each joint. When the propellant is burning and generating hot combustion gases under the enormous pressure necessary to accelerate the SRB, the joint must be sealed to prevent the gases from leaking and possibly damaging exterior parts of the Shuttle. This sealing is accomplished by a primary O-ring backed up by a secondary O-ring (O-rings are widely used in machine design and, when functioning properly, can seal pressures in the range of thousands of psi). An SRM O-ring has been compared to "a huge length of licorice—same color, same diameter (only 0.28")—joined at the ends so it forms a circle 12' across"[10]. SRM O-rings were made of a rubberlike synthetic material called Viton. To prevent the hot combustion gases from contacting and thus degrading the Viton when the propellant was ignited, zinc chromate putty is applied in the region shown in Figure 4 prior to assembly of the SRM segments.

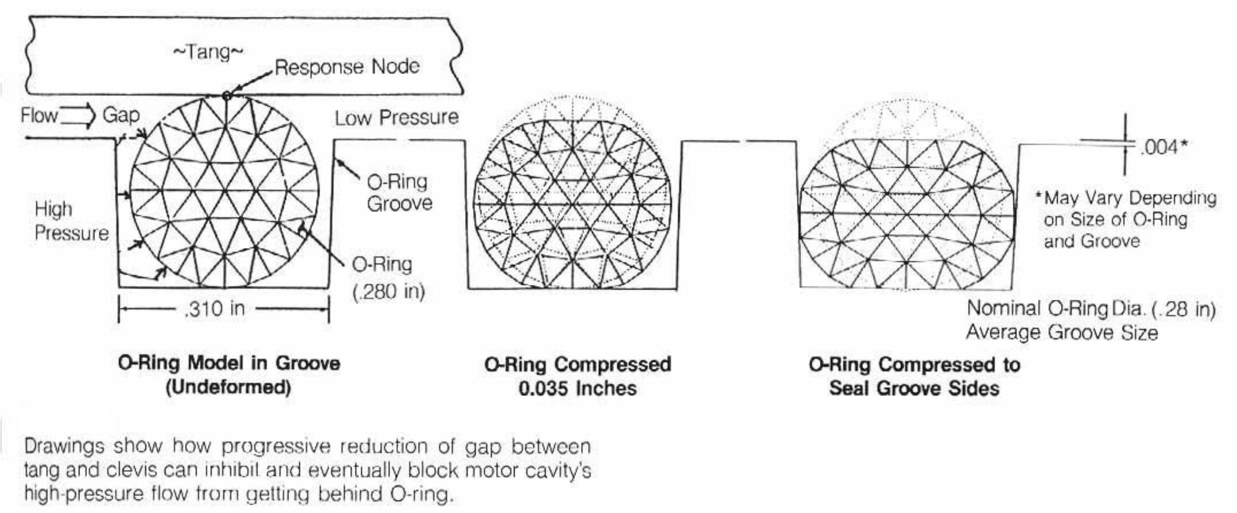


Fig. 5. Effect of Compression of the O-ring in Inhibiting Pressure Actuation

Pressure Actuation of the O-ring Seal

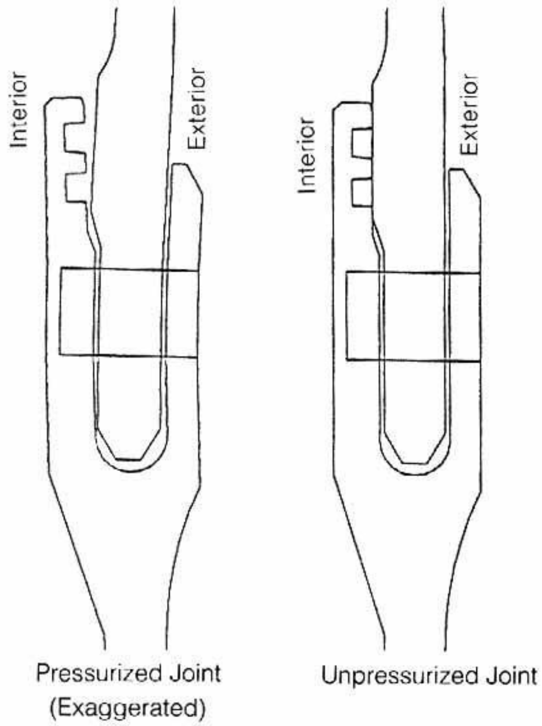
Besides protecting the O-rings from the corrosive effects of the hot combustion gases, the putty is intended to be pushed outward from the combustion chamber during ignition, compress the air ahead of the primary O-ring, and thus force the O-ring into the tang-clevis gap, thereby sealing the gap. This process is referred to as "pressure-actuated sealing." Experiments show that pressure actuation is most effective when the high-pressure air acts over the largest possible portion of the high-pressure side of the O-ring. In the leftmost sketch in Figure 5, for example, the high-pressure side extends from the "Response Node" at the top to the point of tangency at the bottom of the groove. If, however, the O-ring is initially compressed during assembly, then the O-ring may deform sufficiently to cause contact with the left-hand side of the groove, as shown in the rightmost sketch in Figure 5. In that case, the high-pressure air acts over only the surface of the *upper* left-hand side of the O-ring, and pressure actuation of the seal is impaired. This problem is lessened if, upon ignition, the joint gap opens, and the O-ring is able to spring back elastically and lose contact with sides of the groove, as in the middle sketch in Figure 5. However, when the temperature is low, the O-ring loses much of its elasticity and as a result may *retain its compressed shape*, as in the right-hand sketch of Figure 5. This retention of the compressed shape has three unfortunate consequences: 1) pressure actuation is delayed or impaired because the high-pressure air cannot get to the lower left-hand side of the O-ring, 2) pressure actuation is delayed or impaired because the O-ring does not seal the opened gap, and the actuation pressure on the O-ring decreases as the fluid is able to pass by the O-ring, and 3) because of the lack of sealing, compressed air, putty, and then hot combustion gas may blow by through the gap, and in the process, damage or even destroy the O-ring.

In general, pressure actuation was also affected negatively by several other factors, such as the behavior of the putty and the increase in gap size caused by re-use of the SRM. From consideration of all these factors and from observation of the explosion, the Presidential Commission concluded "*that the cause of the Challenger accident was the failure of the pressure* *seal in the aft field joint of the right Solid Rocket Motor* [Italics in the original]. The failure was due to a faulty design unacceptably sensitive to a number of factors. These factors were the effects of temperature, physical dimensions, the character of materials, the effects of reusability, processing, and the reaction of the joint to dynamic loading."[11]

4. History of Problems with Joint Seals

From the very beginning, in 1973, of Thiokol's contract to develop the SRM, problems arose with the joints. The Thiokol design for the SRM was based on the Air Force's Titan III, one of the most reliable solid-fuel rockets produced up to that time. But Thiokol engineers could not simply copy the Titan design—the SRM was larger than the Titan's motor and had to be designed for refurbishment and repeated use. One particular area in which the two motors differed was the field joints, and Thiokol's initial design for the SRM field joints worried engineers at the Marshall Space Flight Center, who were responsible for monitoring Thiokol's contract. Many modifications and reviews of the design ensued, and Thiokol and Marshall finally began various load tests in 1976. Early tests were successful and gave engineers confidence. In an important test in 1977, however, the joint seals surprised the engineers by exhibiting "joint rotation," illustrated in Fig. 6. Of particular concern is the loss of redundancy in the design because not just the primary but also the secondary O-ring is rendered ineffective if the gap opens sufficiently. (It is important to realize the scale of the events being described: the gap between the tang and clevis in the unpressurized joint is tiny: 0.004"; in the pressurized joint the gap was estimated to lie between 0.042" and 0.06,"—caused by a joint rotation that occurs in the first 0.6 seconds of ignition.)[12]

Pressurized Joint Deflection



Drawings show how tang/clevis joint deflects during pressurization to open gap at location of O-ring slots. Inside of motor case and propellant are to left in sketches.

Fig. 6 Joint Rotation

Other sealing problems—some but not all related to joint rotation—such as blow-by, ring charring, ring erosion, loss of resilience of the O-ring material at low temperature, and performance of the putty were observed later in various static tests and launches. Engineers both at Thiokol and at the Marshall were aware of these problems. On July 31, 1985, Roger Boisjoly, a Thiokol engineer specializing in O-rings, wrote a memo to Thiokol vice president Robert Lund with the subject line, "O-ring Erosion/Potential Failure Criticality", after nozzle joint erosion was detected in an SRB:

> “This letter is written to insure that management is fully aware of the seriousness of the current O-ring erosion problem in the SRM joints from an engineering standpoint. “
>
> "The mistakenly accepted position on the joint problem was to fly without fear of failure and to run a series of design evaluations which would ultimately lead to a solution or at least a significant reduction of the erosion problem. This position is now changed as a result of the [51-B] nozzle joint erosion which eroded a secondary O-ring with the primary O-ring never sealing. If the same scenario should occur in a field joint (and it could), then it is a jump ball whether as to the success or failure of the joint because the secondary O-ring cannot respond to the clevis opening rate and may not be capable of

> pressurization. The result would be a catastrophe of the highest order-loss of human life…

Boisjoly urged that a team be set up to work on the O-ring problem, and ended by saying

> "It is my honest and very real fear that if we do not take immediate action to dedicate a team to solve the problem, with the field joint having the number one priority, then we stand in jeopardy of losing a flight along with all the launch pad facilities."[13]

Boisjoly later charged that Thiokol management failed to provide adequate follow-up and support to correct the problem described in his memo.

Readers tempted to commit the retrospective fallacy after reading Boisjoly's memo should note that the memo does not mention temperature effects on the seal.

The years of concern about the sealing problems eventually led to a briefing at NASA Headquarters in Washington on August 19th, 1985, by Marshall and Thiokol, in which they presented both an engineering evaluation and a redesign plan. They noted that only 5 of 111 primary O-rings in field joints and 12 of 47 primary O-rings in nozzle joints had shown erosion in various tests and flights. Thiokol argued that various experimental and flight data verified the safety of the design. They said, however, that the field joint was the "highest concern" and presented plans for improving the joints both with short-term fixes and longer-term fixes that would take over two years to implement. Data from studies by Arnie Thompson (Boisjoly's boss) of the effect of temperature on ring resiliency were presented, but imposing a temperature launch constraint was not mentioned. The review judged that leak checks and careful assembly made it "safe to continue flying [the] existing design." Nevertheless NASA needed "to continue at an accelerated pace to eliminate SRM seal erosion." In the meantime, the risks were considered acceptable.[14]

5. Teleconference

After several delays, the Challenger launch was scheduled for January 28, 1986, at 9:38 AM EST. At about 1 PM on the 27th, however, NASA personnel became concerned about the unusually low temperatures—in the low 20's—predicted for early morning of the next day. A Marshall manager asked Thiokol engineers to review the effect the low temperatures might have on the SRM. Accordingly, a meeting was held at Thiokol's Utah facility. Engineers there stated their concern that the extreme cold would greatly reduce O-ring resiliency and ability to seal the joints. A teleconference among Thiokol, Marshall, and Kennedy personnel was arranged for 5:45 PM EST to assess the situation.

As an aside, we should note that during the televised hearings of the Presidential Commission, commissioner and Nobel prize-winning physicist Richard Feynman created a considerable media stir by placing a piece of an O-ring in a glass of ice water and then showing how the O-ring had lost resiliency. While making good television drama, his demonstration contributed little to advancing public understanding of the Challenger failure: every participant in the teleconference knew that when O-ring material is cold, it stiffens. The whole point of the teleconference was to determine what the extent and effects of that stiffening would be.

At the teleconference, Thiokol engineers made no official recommendation about delaying the launch. The discussion centered on their concerns about the effect of the low temperatures on the O-rings. However, some of the teleconference participants were unable to hear well, because of a poor telephone connection, and some key personnel had not been located in time to be included in the teleconference, so the teleconference was ended, and a second one scheduled for 8:15 PM EST. In the interim, Thiokol engineers had time to organize their data in charts and fax them to Marshall and Kennedy.

A total of thirty-four managers and engineers from Thiokol, Marshall, and Kennedy took part in the second teleconference. Thiokol engineers began the teleconference by discussing the charts that they had faxed to the other teleconference participants. The Thiokol position was that because significant O-ring blow-by and damage had been observed in the coldest previous launch—53°F—the O-ring material would lose much of its resilience and the joint could fail, were the launch to be conducted at a temperature in the 20's or low 30's. When directly asked by Larry Mulloy, Manager of the SRB project at Marshall, Thiokol Vice President Joe Kilminster responded that Thiokol could not recommend launch if the temperature was below 53°F.[15]

After Kilminster's statement, Marshall personnel began challenging the Thiokol position. Of the several objections raised, two particularly stand out. First, the data supporting the relation between temperature and blow-by was ambiguous. Blow-by had once occurred in a launch at 75°F, indicating a cause *independent of temperature*. And even Roger Boisjoly, one of the Thiokol engineers most knowledgeable about sealing and most concerned about the danger to the seal of launching at low temperatures admitted later "I was asked to quantify my concerns, and I said I couldn't, I couldn't quantify it, I had no data to quantify it, but I did say I knew that it was away from goodness in the current data base."[16]

The second objection to the Thiokol position centered on the 53°F limit. For almost three weeks in December, 1985, and two weeks in January, 1986, Cape Canaveral temperatures had been below 53°F, once even reaching 41°F. Launches of the Shuttle Columbia had been scheduled (and repeatedly scrubbed) during these times, yet Thiokol had never voiced concern about the effect of these temperatures on the capacity of the O-rings to seal the joint.

In short, as Thiokol's Larry Sayer later admitted, "[W]e had a very weak engineering position when we went into the telecom." Marshall's Ben Powers similarly observed

> "I don't believe they did a real convincing job of presenting their data … The Thiokol guys even had a chart in there that says temperature of the O-ring is not the only parameter controlling blow-by. In other words, they're not coming in with a real firm statement. They're saying there's other factors. They did have a lot of conflicting data in there. I can't emphasize that enough. Let me quote. On [one] chart of theirs, they had data that said they ran some sub-scale tests down at 30 degrees, and they saw no leakage. Now they're talking out of both sides of their mouth, see. They're saying, "Hey, temperature doesn't have any effect. " Well, I'm sure that that was an extremely important piece of data to Mr. Hardy [Deputy Director of Science and Engineering at Marshall], and certainly to my boss, Mr. McCarty, and Mr. Smith."[17]

Observations like this make it understandable why Marshall's Mulloy complained that Thiokol was, on the eve of a launch, creating a new criterion for launch safety, since no requirement for O-ring temperature to exceed some minimum had ever been previously formulated. Mulloy said, "My God, Thiokol, when do you want me to launch, next April?" George Hardy stated that he was "appalled" at the Thiokol recommendation. Hardy's colleague at Marshall, Keith Coates, later offered a rationale for Hardy's response:

> "George was used to seeing O-rings eroded, and I'm sure that he recognized that it was not a perfect condition, and he did not feel that the 20°F difference between 53°F and 33°F, or somewhere in that range, should make that much difference on seating an O-ring, since you've got 900 psi cramming that O-ring into that groove and it should seal whether it is at 53°F or 33°F. He did say, I do remember a statement something to this effect, 'For God's sake, don't let me make a dumb mistake.' And that was directed to the personnel in the room there at Marshall. I think he fully appreciated the seriousness of it, and so I think that that is on the other side of the coin that he was amazed or appalled at the recommendation."[18]

Thiokol's Kilminster was then asked for his view. He asked for a brief meeting, off-line, with his colleagues in Utah. When the meeting began, Thiokol Senior Vice President Jerry Mason led the discussion. It soon became clear that he was not persuaded by the argument against launching. In response, Roger Boisjoly and Arnie Thompson strongly defended the recommendation not to launch, pointing out that the temperatures predicted for the next day at Cape Canaveral were 20°F below the temperatures at which anyone had had previous launch experience with the O-rings. Then Mason said if the engineers could not come forward with any new data to decide the issue, "We have to make a management decision," indicating that the four senior Thiokol managers present would make the decision (Even though he referred to a "management" decision, all managers involved, at both Thiokol and Marshall, had training and experience as engineers). The four Thiokol managers spoke some more and then held a vote (Boisjoly, Thompson, and the others did not get to vote). Three voted in favor of launching; the fourth, Robert Lund paused. [Recall that Lund had been the recipient of Boisjoly's July, 1985, memo warning of "the seriousness of the current O-ring erosion problem"]. Mason then asked if Lund would "take off his engineering hat and put on his management hat." [In the posttragedy investigation, Mason explained that he meant that the engineering data were not sufficient to decide the issue—a judgment must be made by the people in charge.] Lund voted for launching.

When the teleconference resumed, Kilminster stated Thiokol's new position—in favor of launching—and gave a rationale. Shuttle Projects Manager Stanley Reinartz asked if anybody participating in the teleconference disagreed or had any other comments about the Thiokol recommendation. Nobody spoke. Thus Marshall and Kennedy participants were unaware that some Thiokol engineers continued to disagree with the decision to launch.[19]

Allan McDonald, Thiokol's Director of the SRM project, was stationed at Kennedy and had participated in the teleconference. After the teleconference was finished, he took a strong stand against launching. Because he had not participated in Thiokol's offline discussion, he did not know why Thiokol had changed their position to supporting launching, but he stated clearly that the motor had been qualified only down to 40°F, and further, that "I certainly wouldn't want to be the one that has to get up in front of a board of inquiry if anything happens to this thing and explain why I launched the thing outside of what I thought it was qualified for."[20]

At launch time the next day, the temperature at the launch pad was 36°F.

At this point, the reader might want to recall the myth of perfect engineering practice, discussed in Section 1. The discussion and decision-making process occurring in the teleconference were not unusual. Holding a teleconference before launch was not out of the ordinary but rather was the NASA norm. Similarly, disagreement among engineers working on a large technical project was also the norm, and NASA management routinely subjected any engineer making a recommendation to tough questioning to ensure that the recommendation was based on sound data and logical thinking. What was unusual in this teleconference was that it was the first time in the life of the project that a contractor had made a recommendation not to launch. Before, it had always been NASA that called for a delay.[21]

6. Accident

The Space Shuttle Challenger launch began at 11:38 Eastern Standard Time on January 28th, 1986. The following photos and captions are reproduced, with some modification, from Volume 1 of the *Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident.*[22]

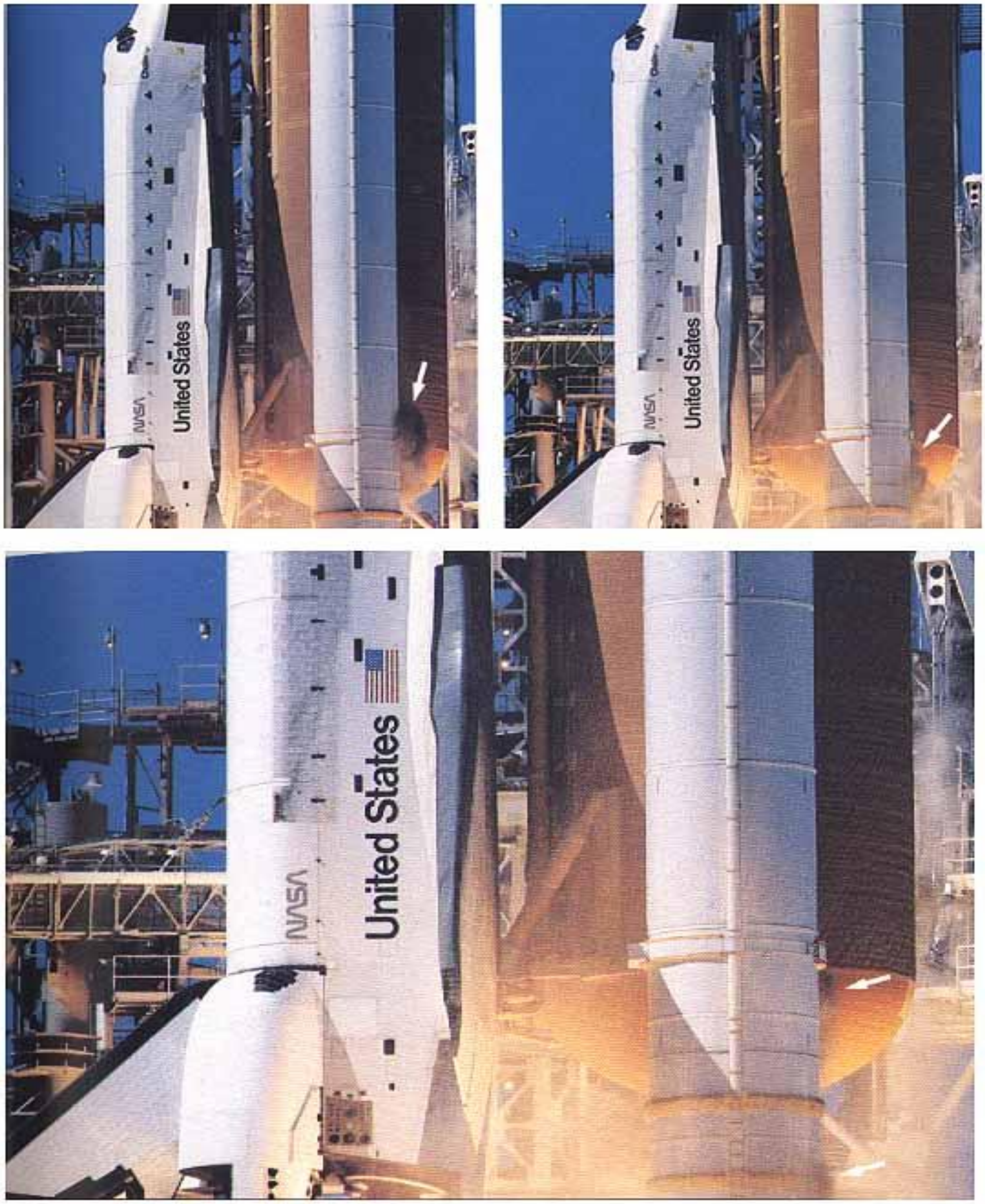


Fig. 7. Immediately after solid rocket motor ignition, dark smoke (arrows) swirled out between the right hand booster and the External Tank. The smoke's origin, behavior and duration were approximated by visual analysis and computer enhancement of film from five camera locations. Consensus: smoke was first discernible at .678 seconds Mission Elapsed Time in the vicinity of the right booster's aft field joint.

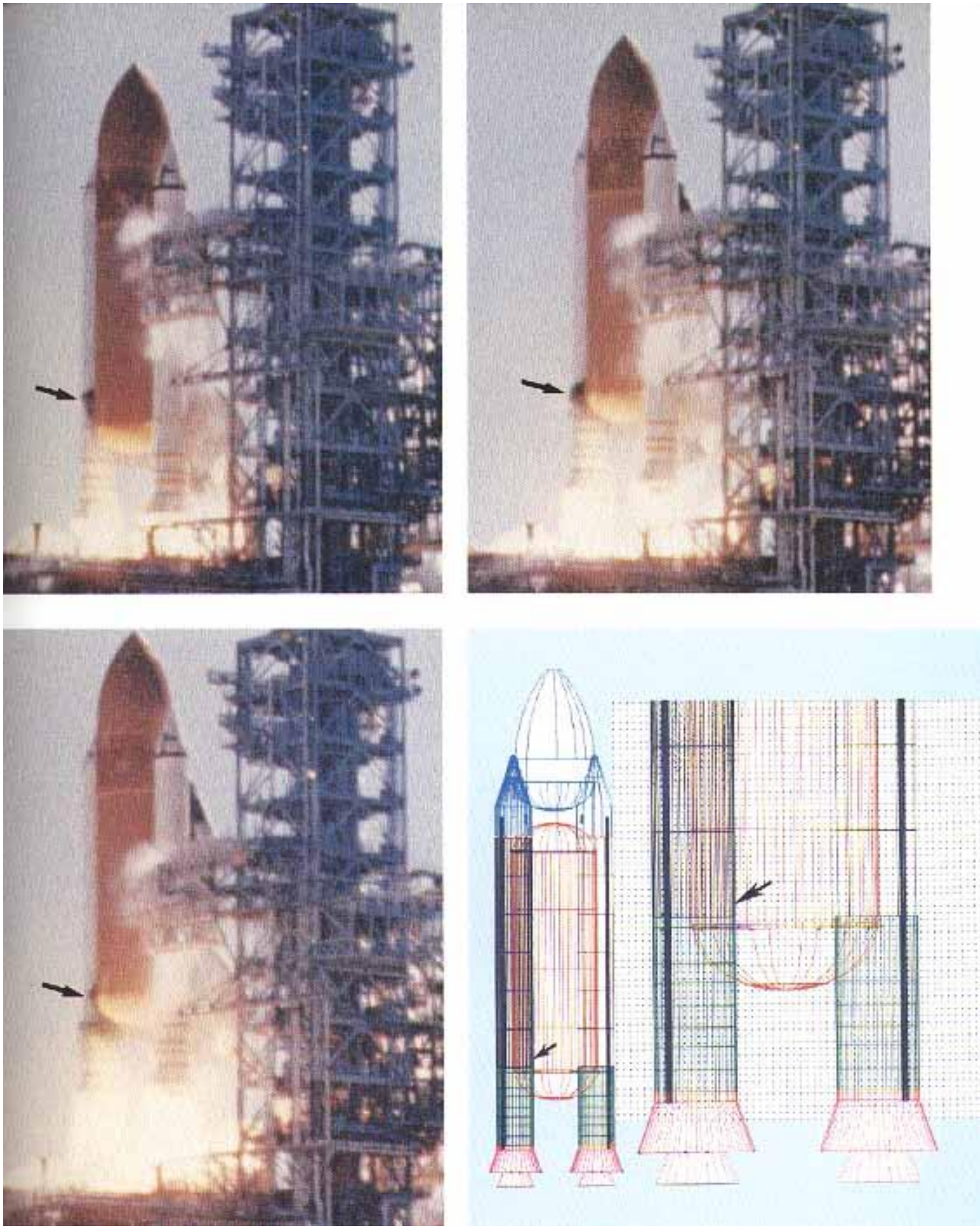


Fig. 8. Multiple smoke puffs are visible in the photo above (arrows). They began at .836 seconds and continued through 2.500 seconds, occurring about 4 times a second. Upward motion of the vehicle caused the smoke to drift downward and blur into a single cloud. Smoke source is shown in the computer generated drawing (far right).

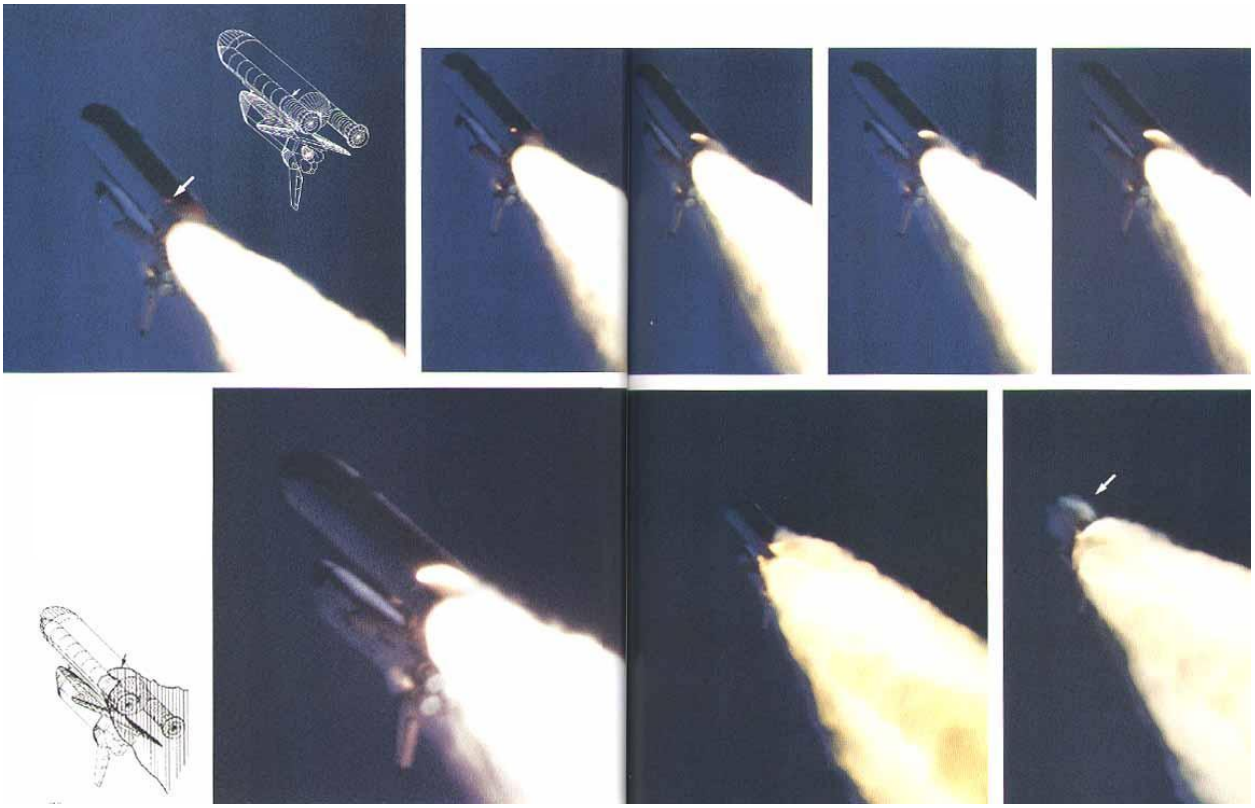


Fig. 9. At 58.788 seconds, the first flicker of flame appeared. Barely visible above, it grew into a large plume and began to impinge on the External Tank at about 60 seconds. Flame is pinpointed in the computer drawing between the right booster and the tank, as in the case of earlier smoke puffs. At far right (arrow), vapor is seen escaping from the apparently breached External Tank.

Fig. 10. Camera views indicate the beginning of rupture of the liquid hydrogen and liquid oxygen tanks within the External Tank. A small flash (arrows above) intensified rapidly, then diminished.

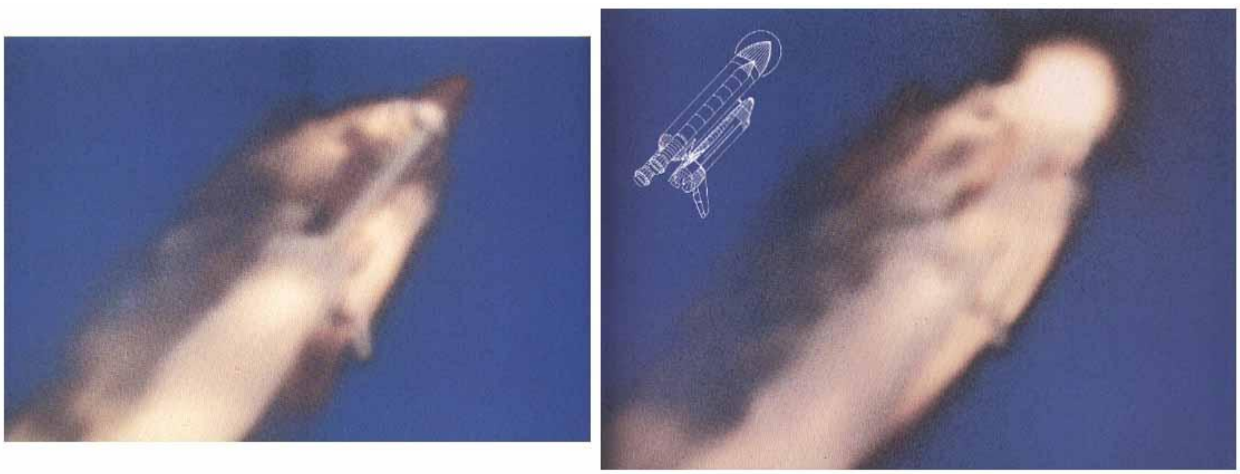


Fig. 11. A second flash, attributed to rupture of the liquid oxygen tank, occurred above the booster/tank forward attachment (left) and grew in milliseconds to the maximum size indicated in the computer drawing.

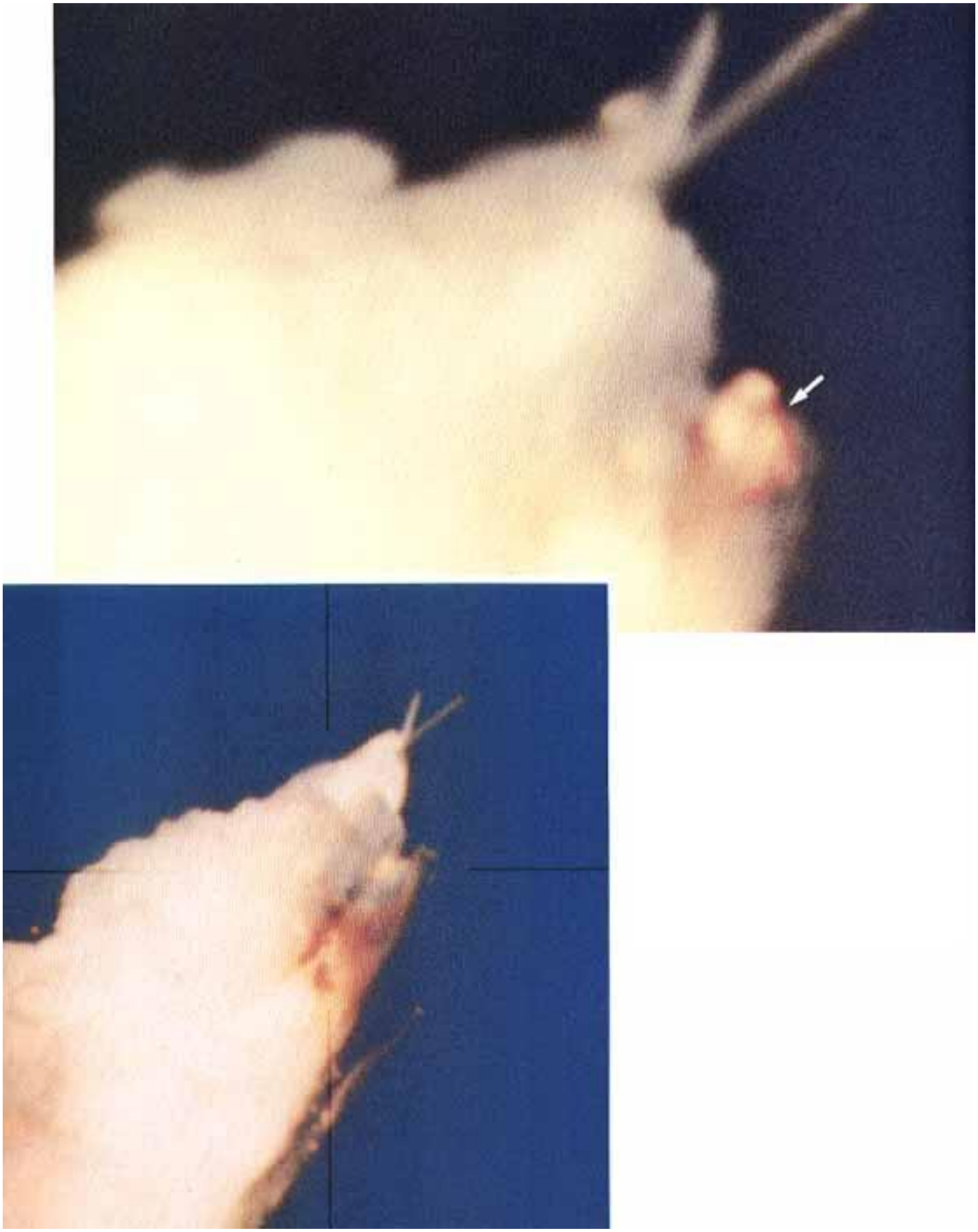


Fig. 12. Structural breakup of the vehicle began at approximately 73 seconds. Fire spread very rapidly. Above [right], a bright flash (arrow) is evident near the nose the Orbiter, suggesting spillage and ignition of the spacecraft's reaction control system propellants. At left, the two Solid Rocket Boosters thrust away from the fire, crisscrossing to from a “V.”

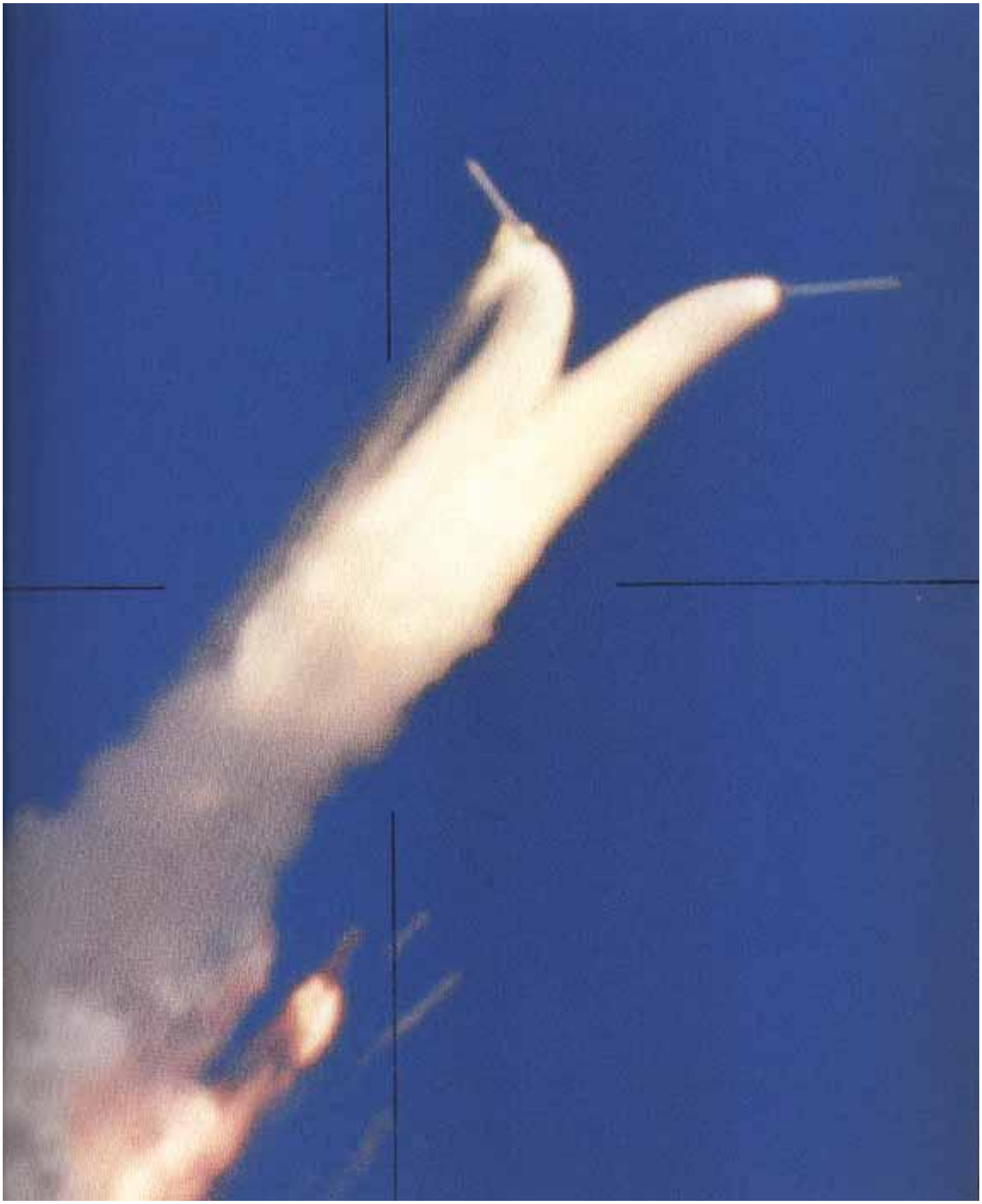


Fig. 13. At right, the boosters diverge farther; the External Tank wreckage is obscured by smoke and vapor. The Orbiter engines still firing, is visible at bottom center.

Fig. 14. At about 76 seconds, unidentifiable fragments of the Shuttle vehicle can be seen tumbling against a background of fire, smoke and vaporized propellants from the External Tank (left).

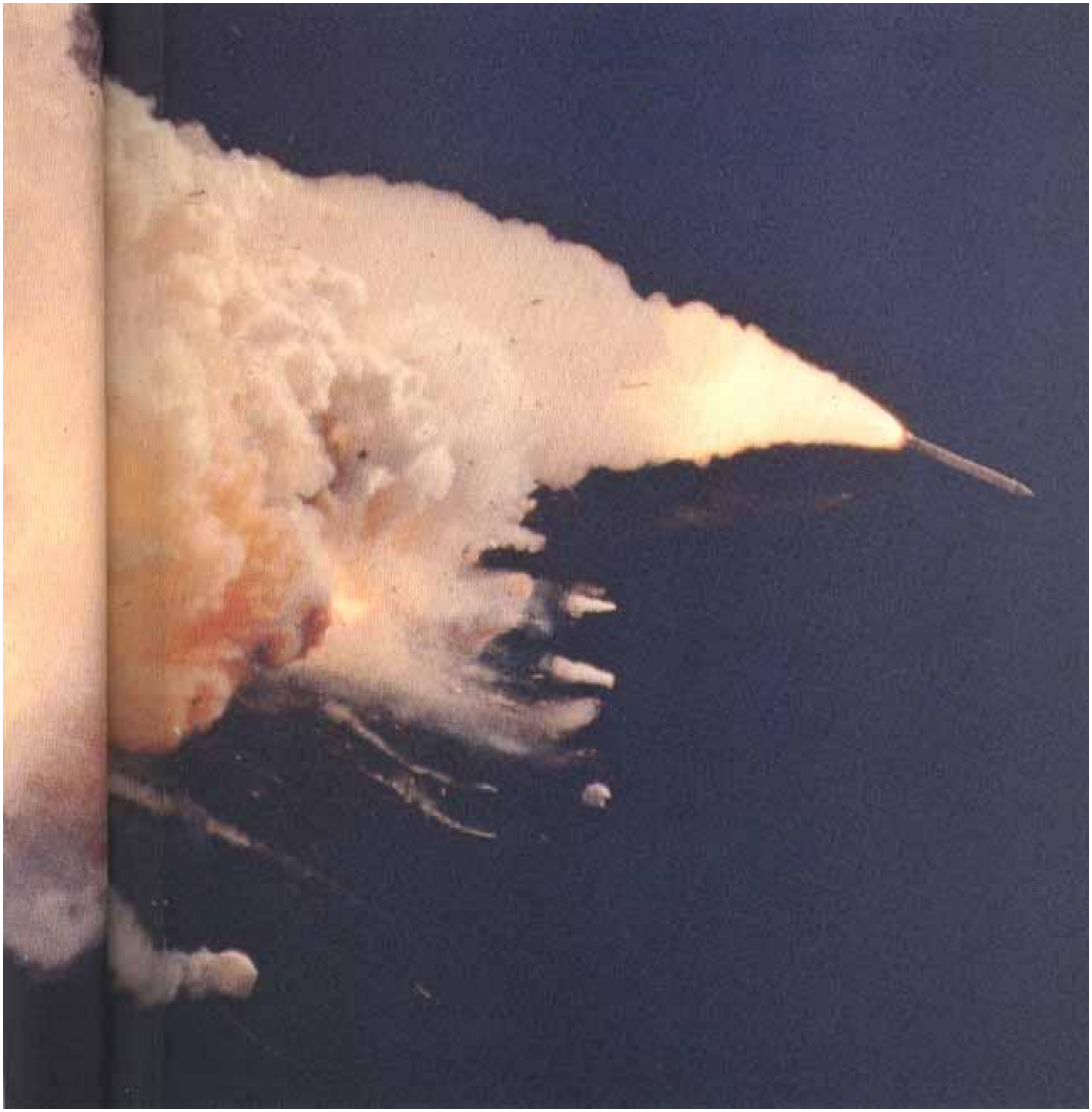


Fig. 15. In the photo at right, the left booster (far right) soars away, still thrusting. The reddish-brown cloud envelops the disintegrating Orbiter. The color is characteristic of the nitrogen tetroxide oxidizer in the Orbiter Reaction Control System propellant.

Fig. 16. Hurtling out of the fireball at 78 seconds are the Orbiter's left wing (top arrow), the main engines (center arrow) and the forward fuselage (bottom arrow). In the photo below [bottom right], it plummets earthward, trailed by smoking fragments of Challenger.

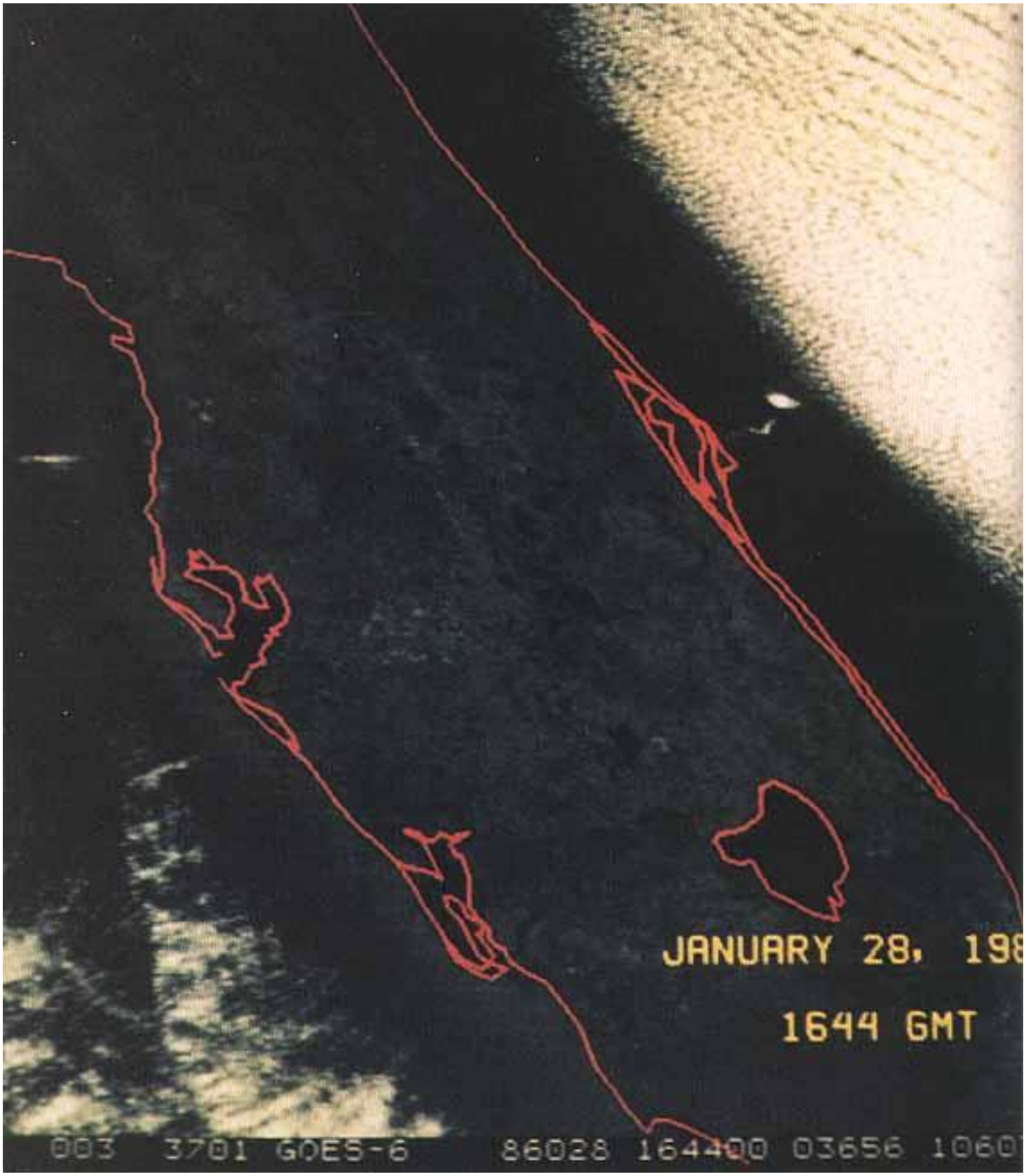


Fig. 17. At 11:44 a.m. Eastern Standard Time, a GOES environment-monitoring satellite operated by the National Oceanic and Atmospheric Administration acquired this image of the smoke and vapor cloud from the 51-L accident. The coast of Florida is outlined.

Fig. 18. Flight crew

Francis R. (Dick) Scobee	Commander
Michael John Smith	Pilot
Ellison S. Onizuka	Mission Specialist One
Judith Arlene Resnik	Mission Specialist Two
Ronald Erwin McNair	Mission Specialist Three
S.Christa McAuliffe	Payload Specialist One
Gregory Bruce Jarvis	Payload Specialist Two

"The consensus of the Commission and participating investigative agencies is that the loss of the Space Shuttle Challenger was caused by a failure in the joint between the two lower segments of the right Solid Rocket Motor. The specific failure was the destruction of the seals that are intended to prevent hot gases from leaking through the joint during the propellant burn of the rocket motor. The evidence assembled by the Commission indicates that no other element of the Space Shuttle system contributed to this failure."[23]

Having established the general outlines of the Challenger story, we now turn to specific ethical issues.

7. Ethical issue: Did NASA knowingly take extra risks because of pressure to maintain Congressional funding?

To sell the Space Shuttle program to Congress initially, NASA had promised that Shuttle flights would become thoroughly routine and economical. Arguing that the more flights taken per year the more routinization and economy would result, NASA proposed a highly ambitious schedule—up to 24 launches per year.[24] But as work on the program proceeded, NASA encountered many delays and difficulties. Concern was voiced in Congress, and NASA officials were worried about continued budget support. To show Congress that progress was being made, NASA planned a record number of launches for 1986. The January Challenger launch was to be the first launch of the year, but unfortunately—and to NASA's further embarrassment—the launch of the Shuttle Columbia scheduled for the previous December was delayed a record seven times (for various reasons, including weather and hardware malfunctions), and finally launched on January 12, 1986, necessitating Challenger's launch date be set back. Thus NASA managers were undeniably under pressure to launch without further delays; a public-relations success was badly needed. This pressure led to managerial wrongdoing, charged John Young, Chief of NASA's Astronaut Office, in an internal NASA memo dated March 4, 1986: "There is only one driving reason that such a potentially dangerous system would ever be allowed to fly—launch schedule pressure."[25] Young's memo was written more than a month after the disaster, so concerns about the retrospective fallacy arise. In any event, the question is, "Did pressure to meet an ambitious launch schedule cause NASA to take risks that otherwise would not have been taken?"

The question is difficult to answer with certainty, but three distinct points can be made:

> 1) *Regardless of ethical considerations*, risking disaster by launching under unsafe conditions simply would have been a bad gamble. Imagine a NASA manager weighing the costs and benefits of risking the flight crew's lives to make the launch schedule. His calculation of the costs would include the probability of detection of his misconduct, if something went wrong. But this situation was not analogous to a dishonest manufacturer's substituting a lower-quality component in an automobile with over 20,000 components; the probability of detection might be low. But if something went wrong with a launch, the probability of detection was 100%. The manager's career would be finished, and he might face criminal charges. Adding this cost to the cost—in moral terms—of the death of the crew and the cost of suspension of the entire program for many months or even years would give a total cost so large that any rational manager would have judged the risk to far outweigh the reward.
>
> 2) The context of Marshall manager Larry Mulloy's remark, "My God, Thiokol, when do you want me to launch, next April?" must be considered. In the words of Marshall's Larry Wear, "Whether his choice of words was as precise or as good or as candid as perhaps he would have liked for them to have been, I don't know. But it was certainly a good, valid point, because the vehicle was designed and intended to be launched year-round. There is nothing in the criteria that says this thing is limited to launching only on warm days. And that would be a serious change if you made it. It would have far reaching effects if that were the criteria, and it would have serious restriction on the whole shuttle program. So the question is certainly germane, you know, what are you

> trying to tell us, Thiokol? Are we limited to launching this thing only on selected days? … The briefing, per se, was addressing this one launch, 51-L. But if you accept that input for 51-L, it has ramifications and implications for the whole 200 mission model, and so the question was fair."[26]
>
> 3) Even though the Presidential Commission's report described at great length the pressure on NASA to maintain an ambitious launch schedule, the report did not identify any individual who ranked budgetary reasons above safety reasons in the decision to launch. Furthermore, "NASA's most outspoken critics—Astronaut John Young, Morton Thiokol engineers Al McDonald and Roger Boisjoly, NASA Resource Analyst Richard Cook, and Presidential Commissioner Richard Feynman, who frequently aired their opinions to the media—did not accuse anyone of knowingly violating safety rules, risking lives on the night of January 27 and morning of January 28 to meet a schedule commitment. … Even Roger Boisjoly … had no ready answer on this point. [When asked] why Marshall managers would respond to production pressures by proceeding with a launch that had the potential to halt production altogether, he was stymied. Boisjoly thought for a while, then responded, 'I don't know.' … The evidence that NASA management violated rules, launching the Challenger for the sake of the Shuttle Program's continued economic viability was not very convincing. Hardy's statement that 'No one in their right mind would knowingly accept increased flight risk for a few hours of schedule' rang true."[27]

After the disaster, other charges appeared in the media. The President's State of the Union address was scheduled for the evening of the 28th, and critics charged that the White House had intervened to insist that the launch occur before the address so that the President could refer to the launch—and perhaps even have a live communication connection with the astronauts during the address. Or perhaps the White House had intervened to ensure that Christa McAuliffe—a high-school teacher who had been included in the flight crew—would be able to conduct and broadcast her Teacher in Space lessons during the week, when children would be in school. If true, these charges would have indicated a clear ethical lapse on the part of NASA management, because they would have violated their duty to make public safety their primary concern. But extensive investigation by the Presidential Commission did not find evidence to support the charges.

8. Ethical issue: Did Thiokol knowingly take extra risks because of fear of losing its contract with NASA?

Shortly before the Challenger launch, word came out that NASA was seeking a second source to supply the SRMs. NASA's actions were taken not out of dissatisfaction with Thiokol's performance but instead "resulted from lobbying by Thiokol's competitors for a piece of NASA's solid rocket market and from desires by Congress to ensure a steady supply of motors for the Shuttle's military payloads."[28] Apparently the existence of a possible second supplier was interpreted by the Presidential Commission as a source of pressure on Thiokol management, with the result, the Commission concluded, that "Thiokol Management reversed its position and recommended the launch of 51-L, at the urging of Marshall and contrary to the views of its engineers in order to accommodate a major customer."[29] The major customer was of course NASA.

On the other hand, however, regardless of the introduction of a second source, Thiokol was to supply NASA with hardware for two more purchases, one for a 60-flight program and another for a separate 90-flight program. Thus the threat posed by a second source was not immediate. Furthermore, in postaccident interviews, the people who had participated in the teleconference explicitly rejected that idea that Thiokol's concern about a possible second-source contractor was a factor in launch decision-making. As Ben Powers of Marshall said, "I knew there was talk of a second source, but I wouldn't have thought it would have made any difference, because they were our only contractor and we need shuttle motors, so, so what? We've got to get them from somewhere. And to get an alternate source you'd have to have somebody that has demonstrated and qualified. There is no one else that can produce that motor at this time. I don't think that had anything to do with this at all. It was strictly dealing with the technical issues."[30]

Finally, the same argument made in the last section about NASA's risking disaster by launching under unsafe conditions being a bad gamble applies equally well to Thiokol. Robert Lund of Thiokol made the point succinctly: "as far as second source on this flight decision, gadzooks, you know, the last thing you would want to do is have a failure."[31]

9. Ethical issue: Was the Principle of Informed Consent Violated?

Scientists conducting an experiment involving human subjects are expected to obtain the "informed consent" of the subjects before the experiment begins. Informed consent refers to the condition that the subjects 1) agree freely and without coercion to participate in the experiment, and 2) have been provided all the information needed and in an understandable form to allow them to make a reasonable decision whether or not to participate in the experiment. Although not usually viewed that way, a Space Shuttle flight certainly has elements of an experiment involving human subjects, and thus the question arises, "Was the principle of informed consent followed in the case of the Challenger crew?" The first requirement, no coercion, was clearly met—to be a crew member was very prestigious, large numbers of people eagerly applied for the positions, and the persons chosen were lauded for their success in being selected. Crew members had back-ups (for use in case of illness, for example), so that had one crew member decided not to participate, he or she would not have been responsible for cancelling the launch for everyone, and so would not have been under pressure for that reason.

The second requirement—that the crew had enough information to decide if they wanted to risk launch—does not appear to have been met. The issue is complicated by the fact, much discussed in the news media, that on the morning of the launch, the flight crew was informed of the ice on the launch pad but was not informed of the teleconference the evening before. But even if they had been told of the teleconference, it is difficult to see how they could have made a reasonable decision about launching. No member of the crew was a specialist in O-rings (Christa McAuliffe, the "Teacher in Space," was not even an engineer or scientist but a high-school social studies teacher). What information could the crew have been given on launch day, or after the teleconference, that they could have possibly digested—in only a few hours—sufficiently to make a reasonable decision? Even if they had had the technical expertise, they also would have encountered the same ambiguities in the data (for example, seal failure at 75°F) and the "very weak engineering position" presented at the teleconference that led the NASA and Thiokol managers to dismiss the concern about the effect of low temperature on the seals. Given that

NASA routinely held teleconferences before launch and these teleconferences contained vigorous questioning about whether it was safe to launch, what reason is there to think that the crew would have been able to discern that the January 27th teleconference raised an issue much more serious than had been raised in previous teleconferences? It seems that it was simply not possible to supply the "informed" half of the "informed consent" requirement.

10. Ethical issue: What role did whistle blowing have in the Challenger story?

The term "whistle blowing" has been attributed to the practice of British policemen in the past who, upon observing someone committing a crime, would blow their whistles to attract the attention of other policemen and civilians in the area. Whistle blowing now has a more specific meaning, with legal ramifications. For example the American Society of Civil Engineers states[32]

> "'Whistle blowing' describes the action taken by an employee who notifies outside authorities that the employer is breaking a law, rule, or regulation or is otherwise posing a direct threat to the safety, health, or welfare of the public. Employees who 'blow the whistle' on their employers are afforded certain protections under U.S. law. If an employee is fired or otherwise retaliated against for whistle blowing, an attorney should be consulted to identify legal protections available to the employee. If it becomes necessary to blow the whistle, the employee must advise the appropriate regulatory agency or a law enforcement agency of the illegal act. Simply complaining to someone inside the company is not whistle blowing and leaves the employee without protection of whistle blower laws."

Note that "complaining to someone inside the company" is not, by this definition, whistle blowing. Thus Roger Boisjoly's attempts before the disaster to get Thiokol management to take action on the O-ring problem, though courageous and admirable, do not constitute whistle blowing.

If Boisjoly can be said to have been a whistle blower, it was because of his actions in the Presidential Commission's investigation *after* the disaster. He repeatedly objected to Thiokol's assertions about the cause of the disaster. He believed that managers at Thiokol and Marshall were trying to minimize the role that temperature played in the failure of the joint seals, and he presented his evidence to the Commission, without first consulting management, and even after managers had complained to him that his statements were harming the company. As time went on, he felt that management was increasingly ignoring him, isolating him from any significant role in the joint redesign work then underway, and generally creating a hostile work environment. In July, 1986, he took an extended sick leave from the company (His colleagues, Arnie Thompson and Allan McDonald, who also had experienced management displeasure as the result of their testimony to the Commission, both continued working at Thiokol after the disaster). In January, 1987, he sued the company for over $2 billion under the False Claims Act for selling defective hardware to NASA. He filed a second suit against the company for $18 million in personal damages—mental suffering and disability that prevented him from returning to productive work; he accused Thiokol of "criminal homicide" in causing the death of the flight crew. After deliberations lasting more than six months, a U.S. District judge dismissed both suits. McDonald commented in his book written many years later that Boisjoly felt he had been harmed by his whistle-blower role: “He told me he was blackballed in the industry by [Thiokol] management, and, indeed, was unsuccessful in finding an engineering job for over a year … He was mentally hurt by the Challenger accident and had a tough time making a living. [He] eventually became a relatively successful expert witness before retiring.”[33] It is not clear that Boisjoly’s difficulties in obtaining a new job were attributable to blackballing by Thiokol: word of his $2 billion lawsuit against his previous employer had appeared in the news media and would have tended to drive away other prospective employers.

In 1988, Boisjoly received the *Scientific Freedom and Responsibility Award* from the American Association for the Advancement of *Science, and the Citation of Honor Award* from The Institute of Electrical and Electronics Engineers.

11. Ethical issue: Who had the right to Thiokol documents relating to the Challenger disaster?

According to newspaper reports, **“**When Boisjoly left Morton Thiokol, he took 14 boxes of every note and paper he received or sent in seven years.”[34] The National Society of Professional Engineers “Code of Ethics for Engineers” states that **“**Engineers' designs, data, records, and notes referring exclusively to an employer's work are the employer's property.”[35] Thus if Boisjoly did not get permission from Thiokol to take the papers, he violated the Code of Ethics. The newspaper reports do not say whether or not he got permission; thus no conclusions can be drawn.

12. Ethical issue: Why are some engineering disasters considered ethical issues and others are not?

The Challenger disaster triggered a tremendous outpouring of activity designed to find the causes of the disaster and to identify the responsible decision makers. A Presidential commission was established. The commission’s report was widely disseminated and analyzed. Congressional hearings were held. Dozens of books and thousands of newspaper, magazine, and scholarly articles were written about the disaster. Thousands of television and radio interviews and discussions took place. Thousands of engineering, business, and philosophy students studied the Challenger disaster in ethics courses. All this attention was the result of a series of engineering decisions that led to the death of seven people.

Compare the attention given to Challenger to the *lack* of attention given to another series of engineering decisions that led to the death of many people. In response to the 1973 oil embargo by OPEC countries, Congress in 1975 passed into law the Corporate Average Fuel Economy (CAFE) standards. The purpose of the standards was to force automobile manufacturers to improve the average fuel mileage of autos and light trucks sold in the United States. The standards did not specify how the improved fuel mileage was to be achieved; that decision was left to the manufacturers and, of course, to their engineers. The engineers saw that the only way to meet the CAFE standards by the required deadlines was to reduce the weight of the vehicles. All other things being equal, however, small cars provide significantly less protection against injury in a collision than large cars. As a result, the CAFE standards led to more consequences than just an improvement in fuel mileage, as described in the findings of a report by a National Research Council panel:

> **“Finding 2.** Past improvements in the overall fuel economy of the nation’s light-duty vehicle fleet have entailed very real, albeit indirect, costs. In particular, all but two members of the [13-member] committee concluded that the downweighting and downsizing that occurred in the late 1970s and early 1980s, some of which was due to CAFÉ standards, probably resulted in an additional 1,300 to 2,600 traffic fatalities in 1993.”[36]

Assuming that the “1,300 to 2,600” fatalities in 1993 were representative of the number of fatalities that have occurred *every* year since the CAFE standards first went into effect, we can estimate that *thousands* of innocent people have died as a result of a policy set by the government and implemented through design changes by engineers in the automobile industry. Small cars are now safer than they were in the 1970s and 1980s, thanks to the work of automotive engineers. Just how much safer is a matter of some debate, but independent of that debate, the question remains why those design improvements weren’t done earlier—as soon as the increase in deaths associated with small cars was noted in the late 1970s.

So the question arises, “Why has the Challenger disaster (seven deaths) been considered by many people as an example of an ethical violation by irresponsible engineers and managers while the CAFE standards disaster (thousands of deaths) has not?” To answer that question, consider the contrasting characteristics of the Challenger and CAFE standards deaths:

> The Challenger deaths involved people already known to the public (through media coverage before the flight); their deaths occurred simultaneously, in one specific location, in front of millions of television viewers and were covered by many reporters; the cause of the deaths could be clearly traced to a particular piece of hardware; and government officials were able to launch a vigorous public investigation because they were unlikely to be blamed for a poor policy decision—that is, the investigation was unlikely to lead to blaming the legislation that the government officials had passed.
>
> The CAFE deaths involved the deaths of people not known to the public; their deaths occurred in many different locations and were spread over many years; no television coverage was present; the link between the standards (and resulting light-weight vulnerable autos) and the deaths was not easily traceable to a particular piece of hardware or design decision; and government officials had a strong incentive to avoid linking the deaths to the CAFE standards (and, by implication to policy that the officials had formulated).

These considerations suggest that the public’s perception plays a role in determining the ethical status of at least some kinds of engineering decisions. Those decisions sharing the characteristics of Challenger described above are subject to ethical scrutiny; those decisions sharing the CAFE characteristics are excused from widespread scrutiny. Many of the Challenger engineers reported personally agonizing over their role in the deaths of seven astronauts. On the other hand, if large numbers of automotive engineers have agonized over the deaths of thousands of drivers of small cars, they have not expressed it publicly. In fact, most automotive engineers would probably be offended were you to suggest that they bear any ethical responsibility for designing cars in which people are more likely to be killed or injured. Their response would probably be something such as, "We design the cars according to government requirements; the public knowingly assumes the risk of driving them." To judge from the limited public controversy (limited compared to the intense publicity accompanying the Challenger disaster) surrounding the CAFE standards deaths, a large majority of the public appears to agree.

13. Concluding remarks

The conventional view—primarily the product of the Presidential Commission report—of the cause of the Challenger disaster is concisely summarized by Vaughan:[37]

> "Accounts emphasizing valiant attempts by Thiokol engineers to stop the launch, actions of a few powerful managers who overruled a unanimous engineering position, and managerial failure to pass information about the teleconference to senior NASA administrators, coupled with news of economic strain and production pressure at NASA, led many to suspect that NASA managers had acted as amoral calculators [persons who ignore moral scruples when pursuing a goal], knowingly violating rules and taking extraordinary risk with human lives in order to keep the shuttle on schedule."

As we have seen, when the details of what engineers actually thought and did are closely examined, the conventional explanation of the disaster is not supported. But if we reject the conventional explanation, can we formulate a better one? Consider the testimony of Larry Mulloy to a Senate committee, "We at NASA," he said, "got into a group-think about this problem. We saw it, we recognized it, we tested it, and we concluded it was an acceptable risk ... When we started down that road we were on the road to an accident."[38] Mulloy's remarks suggest an explanation that is understandable, if not satisfying to the public, which likes explanations with clearly identifiable villains:

> Space shuttle technology was new, complex, and hazardous. Although there were disagreements among conscientious, competent engineers, decision-makers thought that they understood the risks and that the risks were acceptable. The decision-makers were mistaken. But they were not villainous.

Glossary

Challenger 51-L

NASA designation for the Challenger Space Shuttle

Presidential Commission

In February, 1986, President Reagan appointed a commission to investigate the causes of the disaster. William P. Rogers, a former Attorney General, served as the Chair, and the commission is also known as the Rogers Commission.

Kennedy

The Shuttle was launched from the Kennedy Space Center in Cape Canaveral, Florida.

Thiokol

Morton Thiokol Inc. (MTI) was the contractor for the development of the Solid Rocket Booster.

Marshall (MSFC)

The Marshall Space Flight Center in Huntsville, Alabama, had oversight responsibility for Thiokol's work on the booster.

SRB

Solid rocket booster

SRM

Solid rocket motor (part of the SRB)

Notes

1. Presidential Commission on the Space Shuttle Challenger Accident, *Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident* (Washington, D.C.: Government Printing Office, 1986).

2. Diane Vaughan, *The Challenger Launch Decision* (Chicago: University of Chicago Press, 1996).

3. Andrew J. Dunar and Stephen P. Waring, *Power To Explore* -- *History of Marshall Space Flight Center 1960-1990* (Washington, D.C.: Government Printing Office, 1999), 340-379.

4. Vaughan, 460.

5. Presidential Commission, *Report* 1:40.

6. Vaughan, 200.

7. Ibid., 68-70.

8. *NASA's Response to the Committee's Investigation of the "Challenger" Accident*. Hearing conducted by the House of Representatives Committee on Science, Space, and Technology, February 26, 1987.

9. Allan J. McDonald, *Truth, Lies, and O-Rings.* (Gainsville, FL: University Press of Florida, 2009), 64-65.

10. Vaughan, 40.

11. Presidential Commission, *Report* 1:69.

12. Dunar, 341-343.

13. Vaughan, 447.

14. Dunar, 363.

15. Vaughan, 306.

16. Ibid., 304.

17. Ibid., 307.

18. Ibid., 314.

19. Ibid., 323.

20. Ibid., 327.

21. Ibid., 305.

22. Presidential Commission, *Report*

23. Ibid., 1:40.

24. Ibid., 164.

25. NASA SP-4407, *Exploring the Unknown. Selected Documents in the History of the U.S. Civil Space Program. Vol. IV: Accessing Space*, ed. John M. Logsdon with Ray A. Williamson, Roger D. Launius, Russell J. Acker, Stephen J. Garber, and Jonathan L. Friedman (Washington, D.C.: NASA History Division, Office of Policy and Plans, 1999), 379.

26. Vaughan, 311.

27. Ibid., 55-56.

28. Dunar, 369.

29. Presidential Commission, *Report* 1:105.

30. Vaughan, 337-338.

31. Ibid., 338.

32. "*ASCE Guidelines for Professional Conduct for Civil Engineers.*" (2008 version). <http://www.asce.org/uploadedFiles/Ethics_-_New/ethics_guidelines010308v2.pdf> (Accessed Dec. 14, 2010).

33. McDonald, 554-555,

34. “Chapman receives papers from Challenger disaster.” (2010). Orange County Register. <http://www.ocregister.com/news/boisjoly-248703-boyd-chapman.html?plckFindCommentKey=CommentKey:a00a912b-593e-4236-aa06-d85e9d68d755 > (Accessed Dec. 14, 2010).

35. “*NSPE Code of Ethics for Engineers*.” (2007 version). < http://www.nspe.org/ethics/codeofethics/index.html > (Accessed Dec. 14, 2010).

36. Committee on the Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards* (Washington, D.C.: National Academy Press, 2002).

37. Vaughan, 278.

38. Dunar, 378.

About the Author

Dr. Rossow holds B.S., M.S., and Ph.D. degrees from the University of Michigan and is a licensed Professional Engineer in Illinois. He taught civil engineering for over 35 years, including six years at Washington University in St. Louis and 29 years at Southern Illinois University Edwardsville, where he was the Chair of the Civil Engineering Department for ten years. His areas of expertise are in civil engineering and mechanics. He has consulted for various organizations, including government agencies and an international offshore drilling company. He has published many journal articles and technical reports and has developed software for engineering education. He is especially interested in writing for practicing engineers and engineering students about issues such as engineering ethics, professionalism, safety, and the role of engineers in an open, democratic society. He is the author of three Kindle books, *In Trouble with the PE Licensing Board*, *Improper Work Practices and OSHA's Fatal Facts*, and *The Challenger Disaster and Engineering Ethics*, and also publishes engineering software through the website http://www.engineeringexceltemplates.com

End

Go To Table of Contents