The Challenger Case

Several months before the destruction of *Challenger*, NASA historian Alex Roland wrote the following in a critical piece about the space shuttle program:

[18] Stephen H. Unger, *Controlling Technology: Ethics and the Responsible Engineer*, 2nd ed. (New York: John Wiley & Sons, 1994), pp. 210–15. See also Paula Wells, Hardy Jones, and Michael Davis, *Conflicts of Interest in Engineering* (Dubuque, IA: Kendall/Hunt, 1986).

> The American taxpayer bet about $14 billion on the shuttle. NASA bet its reputation. The Air Force bet its reconnaissance capability. The astronauts bet their lives. We all took a chance.
>
> When John Young and Robert Crippen climbed aboard the orbiter *Columbia* on April 12, 1981, for the first shuttle launch, they took a bigger chance than any astronaut before them. Never had Americans been asked to go on a launch vehicle's maiden voyage. Never had astronauts ridden solid propellant rockets. Never had Americans depended on an engine untested in flight.[19]

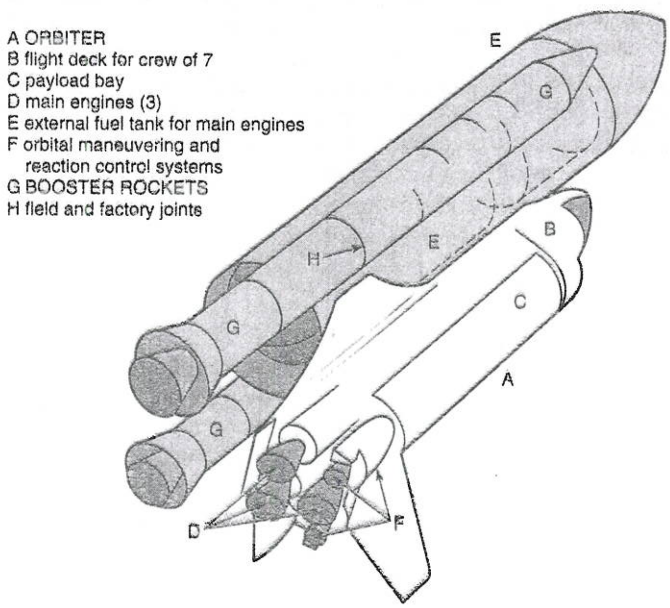
Most of Alex Roland's criticism was directed at the economic and political aspects of the shuttle program that was supposed to become a self-supporting operation but never gave any indication of being able to reach that goal. Without a national consensus to back it, the program became a victim of year-by-year funding politics.

The *Columbia* and its sister ships, *Challenger, Discovery,* and *Endeavor,* are delta-wing craft with a huge payload bay. Early, sleek designs had to be abandoned to satisfy U.S. Air Force requirements when the Air Force was ordered to use the NASA shuttle instead of its own expendable rockets for launching satellites and other missions. As shown in Figure 3–2, each orbiter has three main engines fueled by several million pounds of liquid hydrogen; the fuel is carried in an immense, external, divided fuel tank, which is jettisoned when empty. During liftoff, the main engines fire for about 8.5 minutes, although during the first 2 minutes of the launch, much of the thrust is provided by two booster rockets. These are of the solid-fuel type, each burning a one-million-pound load of a mixture of aluminum, potassium chloride, and iron oxide.

The casing of each booster rocket is about 150 feet long and 12 feet in diameter. It consists of cylindrical segments that are assembled at the launch site. The four field joints use seals composed of pairs of O-rings made of vulcanized rubber. The O-rings work in conjunction with a putty barrier of zinc chromide.

The shuttle flights were successful, though not as frequent as had been hoped. NASA tried hard to portray the shuttle program as an operational system that could pay for itself. Some Reagan administration officials had even suggested that the operations be turned over to an airline. Aerospace engineers intimately involved in designing, manufacturing, assembling, testing, and operating the shuttle still regarded it as an experimental undertaking in 1986. These engineers were employees of manufacturers, such as Rockwell International (orbiter and main rocket)

[19] Alex Roland, "The Shuttle, Triumph or Turkey?" *Discover,* November 1985, pp. 29–49.



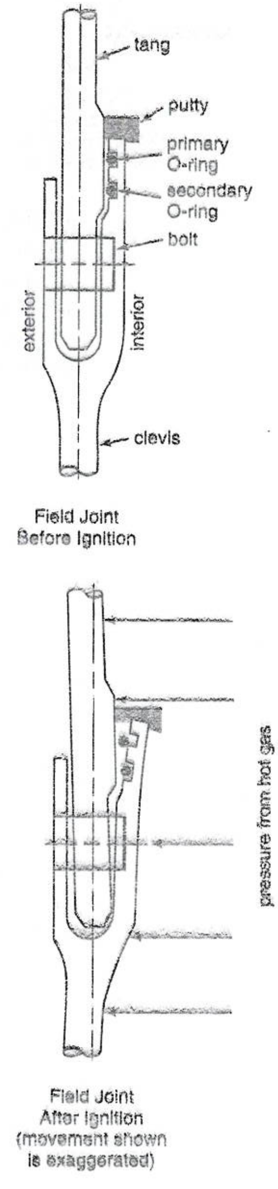


Figure 3–2
Space shuttle *Challenger.*

and Morton-Thiokol (booster rockets), or they worked for NASA at one of its several centers: Marshall Space Flight Center, Huntsville, Alabama (responsible for the propulsion system); Kennedy Space Center, Cape Kennedy, Florida (launch operations); Johnson Space Center, Houston, Texas (flight control); and the office of the Chief Engineer, Washington, D.C. (overall responsibility for safety, among other duties).

After embarrassing delays, *Challenger*'s first flight for 1986 was set for Tuesday morning, January 28. But Allan J. McDonald, who represented Morton-Thiokol at Cape Kennedy, was worried about the freezing temperatures predicted for the night. As his company's director of the solid-rocket booster project, he knew of difficulties that had been experienced with the field joints on a previous cold-weather launch when the temperature had been mild compared to what was forecast. He therefore arranged a teleconference so that NASA engineers could confer with Morton-Thiokol engineers at their plant in Utah.

Arnold Thompson and Roger Boisjoly, two seal experts at Morton-Thiokol, explained to their own colleagues and managers as well as the NASA representatives how, upon launch, the booster rocket walls bulge and the combustion gases can blow past one or even both of the O-rings that make up the field joints (see Figure 3–2). The rings char and erode, as had been observed on many previous flights. In cold weather, the problem is aggravated because the rings and the putty packing are less pliable then. But

> . . . only limited consideration was given to the past history of O-ring damage in terms of temperature. The managers compared as a function of temperature the flights for which thermal distress of O-rings had been observed [Figure 3–3]—not the frequency of occurrence based on all flights. When the entire history of flight experience is considered, including "normal" flights with no erosion or blow-by, the comparison is substantially different [Figure 3–4]. Consideration of the entire launch temperature history indicates that the probability of O-ring distress is increased to almost a certainty if the temperature of the joint is less than 65.[20]

If the graph depicted in Figure 3–4 and other supporting renditions (such as Figure 3–5 of later date) had been available at the meeting, upper management might just have seen the problem of cold O-rings more clearly, but with launch time approaching, deliberations were cut short.

The engineering managers, Bob Lund (vice president of engineering) and Joe Kilminster (vice president for booster rockets), agreed that there was a problem with safety. The team from Marshall Space Flight Center was incredulous. Since the specifications called for an operating temperature of the solid fuel prior to combustion of 40 to 90 degrees Fahrenheit, one could surely

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[20] Rogers Commission Report, *Report of the Presidential Commission on the Space Shuttle* Challenger *Accident* (Washington, DC: U.S. Government Printing Office, 1986).

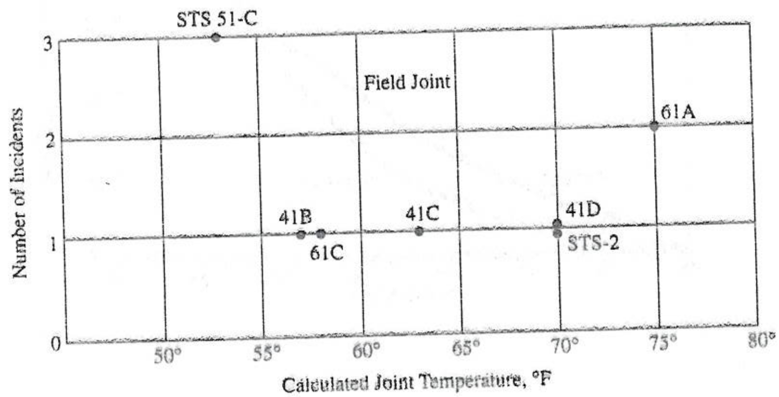

Figure 3–3
Plot of flights *with* incidents of O-ring thermal distress: Number of O-rings affected plotted against temperature. (*Source: Rogers Commission Report*, Report of the Presidential Commission on the Space Shuttle *Challenger* Accident [*Washington, DC: U.S. Government Printing Office, 1986*].)

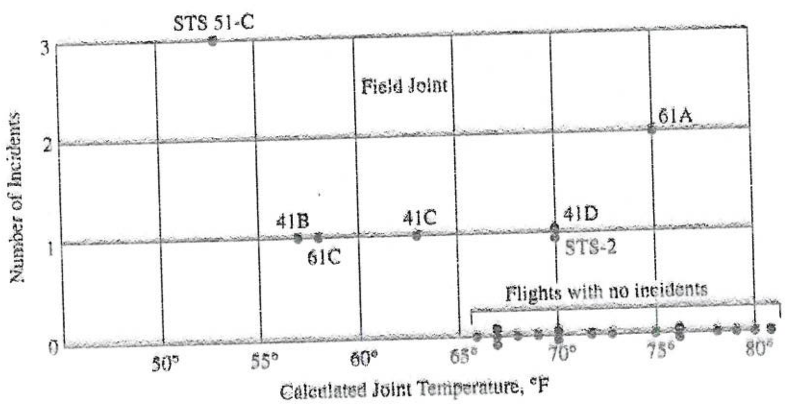

Figure 3–4
Plot of flights *with and without* incidents of O-ring thermal distress. (*Source: Rogers Commission Report*, Report of the Presidential Commission on the Space Shuttle *Challenger* Accident [*Washington, DC: U.S. Government Printing Office, 1986*].)

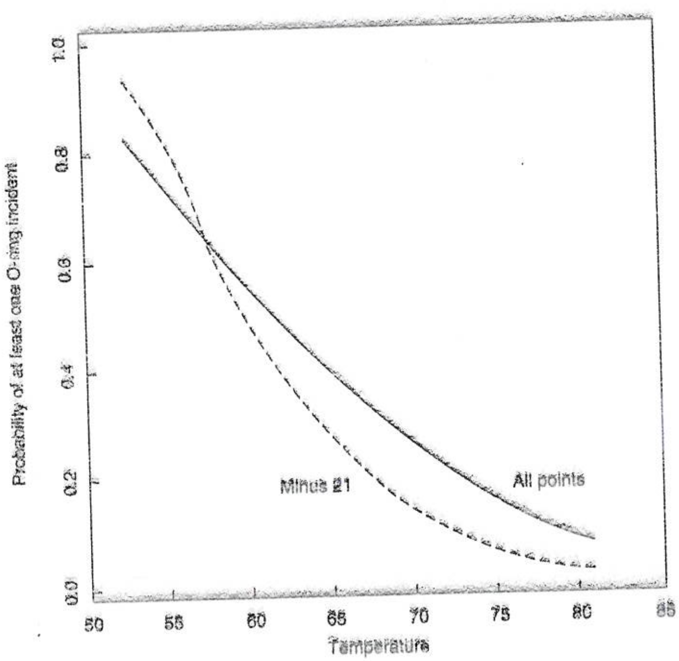

Figure 3–5
Binomial-logit model based on all data remaining after removing flight #61A in Figure 3–4, and also *with* flight 61A (data point #21). The ordinate gives the probability of distress of at least one O-ring. (*Source: Siddharta R. Dalal, Edward B. Fowlkes, and Bruce Hoadley, "Risk Analysis of the Space Shuttle: Pre-Challenger Prediction of Failure,"* Journal of the American Statistical Association 84, [*December 1989*], *pp. 945–57*.)

allow lower or higher outdoor temperatures, notwithstanding Boisjoly's testimony and recommendation that no launch should occur at less than 53 degrees. They were clearly annoyed at facing yet another postponement.

Top executives of Morton-Thiokol were also sitting in on the teleconference. Their concern was the image of the company, which was in the process of negotiating a renewal of the booster rocket contract with NASA. During a recess, Senior Vice President Jerry Mason turned to Bob Lund and told him "to take off your engineering hat and put on your management hat." It was a subsequent vote (of the managers only) that produced the company's official finding that the seals could not be shown to be unsafe. The engineers' judgment was not considered sufficiently weighty. At Cape Kennedy, Allan McDonald refused to sign the formal recommendation to launch; Joe Kilminster had to. Accounts of the *Challenger* disaster tell of the cold Tuesday morning, the high seas that forced the recovery ships to seek coastal shelter, the ice at the launch site, and the concern expressed by Rockwell engineers that the ice might shatter and hit the orbiter or rocket casings.[21] The inability of these engineers to *prove* that the liftoff would be unsafe was taken by NASA as an approval by Rockwell to launch.

The countdown ended at 11:38 A.M. The temperature had risen to 36 degrees. As the rockets carrying *Challenger* rose from the ground, cameras recorded puffs of smoke that emanated from one of the field joints on the right booster rocket. Soon these turned into a flame that hit the external fuel tank and a strut holding the booster rocket. The hydrogen in the tank caught fire; the booster rocket broke loose and smashed into *Challenger*'s wing and then into the external fuel tank. At 76 seconds into the flight, by the time *Challenger* and its rockets had reached 50,000 feet, it was totally engulfed in a fireball. The crew cabin separated and fell into the ocean, killing all aboard: mission commander Francis (Dick) Scobee; pilot Michael Smith; mission specialists Gregory Jarvis, Ronald McNair, Ellison Onizuka, and Judith Resnick; and "teacher in space" Christa MacAuliffe.

President Reagan was to give his State of the Union message later that day. He had to change the tone of his prepared remarks on the shuttle flight and its first civilian passenger.

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[21] Malcolm McConnell, *Challenger, a Major Malfunction* (Garden City, NY: Doubleday, 1987); Rosa Lynn B. Pinkus, Larry J. Shuman, Norman P. Hummon, and Harvey Wolfe, *Engineering Ethics: Balancing Cost, Schedule, and Risk—Lessons Learned from the Space Shuttle* (Cambridge: Cambridge University Press, 1997).

Safety Issues

Unlike the *three-stage rockets* that carried astronauts to the moon, the *space shuttle* could be involved in a simultaneous (inadvertent) ignition of all fuel carried aloft. An explosion close to the ground can have catastrophic effects. The crew had no escape mechanism, although McDonnell Douglas, in a losing shuttle proposal, had designed an abort module with its own thruster. It would have allowed the separation of the orbiter, triggered (among other events) by a field-joint leak. But such a safety measure was rejected as too expensive because of an accompanying reduction in payload.

Working with such constraints, why was safe operation not stressed more? First of all, we must remember that the shuttle program was indeed still a truly experimental and research undertaking. Next, it is quite clear that the members of the crews knew that they were embarking on dangerous missions. But it has also been revealed that the *Challenger* astronauts were not informed of particular problems such as the field joints. They were not asked for their consent to be launched under circumstances that experienced engineers had claimed to be unsafe.

The reason for the rather cavalier attitude toward safety is revealed in the way NASA assessed the system's reliability. For instance, recovered booster rocket casings had indicated that the field-joint seals had been damaged in many of the earlier flights. The waivers necessary to proceed with launches had become mere gestures. Richard Feynman made the following observations as a member of the Presidential Commission on the Space Shuttle *Challenger* Accident (called the Rogers Commission, after its chairman):

> I read all of these [NASA flight readiness] reviews and they agonize whether they can go even though they had some blow-by in the seal or they had a cracked blade in the pump of one of the engines . . . and they decide "yes." Then it flies and nothing happens. Then it is suggested . . . that the risk is no longer so high. For the next flight we can lower our standards a little bit because we got away with it last time. . . . It is a kind of Russian roulette.[22]

Since the early days of unmanned space flight, about 1 in every 25 solid-fuel rocket boosters had failed. Given improvements over the years, Feynman thought that 1 in every 50 to 100 might be a reasonable estimate now. Yet NASA counted on only

[22] Rogers Commission Report, *Report of the Presidential Commission.*

1 crash in every 100,000 launches. Queried about these figures, NASA Chief Engineer Milton Silveira answered: "We don't use that number as a management tool. We know that the probability of failure is always sitting there."[23] So where was this number used? In a risk analysis needed by the Department of Energy to assure everyone that it would be safe to use small atomic reactors as power sources on deep-space probes and to carry both aloft on a space shuttle. As luck would have it, *Challenger* was not to carry the 47.6 pounds of lethal plutonium-238 until its next mission with the Galileo probe on board.[24]

Another area of concern was NASA's unwillingness to wait out risky weather. When serving as weather observer, astronaut John Young was dismayed to find his recommendations to postpone launches disregarded several times. Things had not changed much by March 26, 1987, when NASA ignored its devices monitoring electric storm conditions, launched a Navy communications satellite atop an Atlas-Centaur rocket, and had to destroy the $160 million system when it veered off course after being hit by lightning. The storm monitors had been installed after an *Apollo* command module almost had its moon trip aborted 18 years earlier because of storm conditions. Weather, incidentally, could be held partially responsible for the shuttle disaster because a strong wind shear may have contributed to the rupturing of the weakened O-rings.[25]

Veteran astronauts were also dismayed at NASA management's decision to land at Cape Kennedy as often as possible despite its unfavorable landing conditions, including strong crosswinds and changeable weather. The alternative, Edwards Air Force Base in California, is a better landing place but requires a piggyback ride for the shuttle on a Boeing 747 home to Florida. This costs time and money.

In 1982, Albert Flores had conducted a study of safety concerns at the Johnson Space Center. He found its engineers to be strongly committed to safety in all aspects of design. When they were asked how managers might further improve safety awareness, there were few concrete suggestions but many comments

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[23] Eliot Marshall, "Feynman Issues His Own Shuttle Report, Attacking NASA Risk Estimates," *Science* 232 (June 1986), p. 1596. See also Richard P. Feynman's rendition on the shuttle fiasco and the Rogers Commission workings in *What Do You Care What Other People Think?*, as told to Ralph Leighton (New York: W. W. Norton & Co., 1988).

[24] Karl Grossman, "Red Tape and Radioactivity," *Common Cause*, July–August 1986, pp. 24–27.

[25] Trudy E. Bell, "Wind Shear Cited as Likely Factor in Shuttle Disaster," *The Institute* (IEEE) 11 (May 1987), p. 1. For effects of lightning, see Eliot Marshall, "Lightning Strikes Twice at NASA," *Science* 236 (May 1987), p. 903.

on how safety concerns were ignored or negatively impacted by management. One engineer was quoted as saying, "A small amount of professional safety effort and upper management support can cause a quantum safety improvement with little expense."[26] This points to the important role of management in building a strong sense of responsibility for safety first and for schedules second.

The space shuttle's field joints are designated "criticality 1," which means there is no backup. Therefore, a leaky field joint will result in failure of the mission and loss of life. There are 700 items of criticality 1 on the shuttle. A problem with any one of them should have been cause enough to do more than just launch more shuttles without modification while working on a better system. Improved seal designs had already been developed, but the new rockets would not have been ready for some time. In the meantime, the old booster rockets should have been recalled.

At Morton-Thiokol, Roger Boisjoly's personal concern had been heightened by his memory of the DC-10 crash over Paris. That accident had shown him how known defects can be disregarded in a complex organization. For this reason, he had started a journal in which he recorded all events associated with the seals.[27] But he probably did not feel that he had the kind of professional backing that would allow him to go beyond his organization directly to the astronauts.

In several respects, the ethical issues in the *Challenger* case resemble those of other such cases. Concern for safety gave way to institutional posturing. Danger signals did not go beyond Morton-Thiokol and Marshall Space Flight Center in the *Challenger* case. No effective recall was instituted. There were concerned engineers who spoke out, but ultimately they felt it only proper to submit to management decisions.

One notable aspect of the *Challenger* case is the late-hour teleconference that Allan McDonald had arranged from the *Challenger* launch site to get knowledgeable engineers to discuss the seal problem from a technical viewpoint. This tense conference did not involve lengthy discussions of ethics, but it revealed the virtues (or lack thereof) that allow us to distinguish between the "right stuff" and the "wrong stuff." This is well described by one aerospace engineer as arrogance, specifically "The arrogance that prompts higher-level decision makers to pretend that factors other than engineering judgment should influence flight safety

[26] Albert Flores, ed., *Designing for Safety: Engineering Ethics in Organizational Contexts* (Troy, NY: Rensselaer Polytechnic Institute, 1982), p. 79; Feynman, *What Do You Care What Other People Think?*

[27] Caroline Whitbeck, "Moral Responsibility and the Working Engineer," *Books and Religion* 15 (March–April 1987), p. 3.

decisions and, more important, the arrogance that rationalizes overruling the engineering judgment of engineers close to the problem by those whose expertise is naive and superficial by comparison."[28] Included, surely, is the arrogance of those who reversed NASA's (paraphrased) motto, "Don't fly if it cannot be shown to be safe" to "Fly unless it can be shown not to be safe."

At Morton-Thiokol, some of the vice presidents in the space division have been demoted. The engineers who were outspoken at the prelaunch teleconference and again before the Rogers Commission kept their jobs at the company because of congressional pressure, but their jobs are of a pro forma nature. In a speech to engineering students at the Massachusetts Institute of Technology a year after the *Challenger* disaster, Roger Boisjoly said: "I have been asked by some if I would testify again if I knew in advance of the potential consequences to me and my career. My answer is always an immediate yes. I couldn't live with any self-respect if I tailored my actions based upon potential personal consequences as a result of my honorable actions."[29]

Today NASA has a policy that allows aerospace workers with concerns to report them anonymously to the Batelle Memorial Institute in Columbus, Ohio, but open disagreement still invited harassment for a number of years.

Discussion Topics

1. Chairman Rogers asked Bob Lund: "Why did you change your decision [that the seals would not hold up] when you changed hats?" What might motivate you, as a midlevel manager, to go along with top management when told to "take off your engineering hat and put on your management hat"? Applying the engineering-as-experimentation model, what might responsible experimenters have done in response to the question?
2. Under what conditions would you say it is safe to launch a shuttle without an escape mechanism for the crew?
3. Discuss the role of the astronauts in shuttle safety. To what extent should they (or at least the orbiter commanders) have involved themselves more actively in looking for safety defects in design or operation?
4. Consider the following actions or recommendations and suggest a plan of action to bring about safer designs and operations in a complex organization.

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[28] Calvin E. Moeller, "*Challenger* Catastrophe," *Los Angeles Times*, Letters to the Editor, March 11, 1986.

[29] Roger M. Boisjoly, Speech on shuttle disaster delivered to MIT students, January 7, 1987. Printed in *Books and Religion* 15 (March–April 1987), p. 3.

(a) Lawrence Mulloy represented Marshall Space Flight Center at Cape Kennedy. He did not tell Arnold Aldrich from the National Space Transportation Program at Johnson Space Center about the discussions regarding the field-joint seals even though Aldrich had the responsibility of clearing *Challenger* for launch. Why? Because the seals were "a Level III issue," and Mulloy was at Level III, while Aldrich was at a higher level (Level II), which ought not to be bothered with such details.

(b) The Rogers Commission recommended that an independent safety organization directly responsible to the NASA administrator be established. An anonymous reporting scheme now exists for aerospace industry employees working on NASA projects.

(c) Tom Peters advises managers to "involve everyone in everything. . . . Boldly assert that there is no limit to what the average person can accomplish if thoroughly involved." [30]

5. On October 4, 1930, the British airship *R 101* crashed about eight hours into its maiden voyage to India. Of the 54 persons aboard, only 6 survived. Throughout the craft's design and construction, Air Ministry officials and their engineers had been driven by strong political and competitive forces. Nevil Shute, who had worked on the rival, commercial *R 100*, wrote in his memoir, *Slide Rule*, that "if just one of [the men at the Air Ministry] had stood up [at a conference with Lord Thomson] and had said, 'This thing won't work, and I'll be no party to it. I'm sorry, gentlemen, but if you do this, I'm resigning,' . . . the disaster would almost certainly have been averted. It was not said, because the men in question put their jobs before their duty."[31] Examine the *R 101* case, and compare it with the *Challenger* case, including the pressures not to delay the flight.

[30] Tom Peters, *Thriving on Chaos* (New York: Alfred A. Knopf, 1987).

[31] Nevil Shute, *Slide Rule* (New York: William Morrow, 1954), p. 140. Also see Henry Cord Meyer, "Politics, Personality, and Technology: Airships in the Manipulations of Dr. Hugo Eckener and Lord Thomson, 1919–1930," *Aerospace Historian* (September 1981), 165–72; Arthur M. Squires, *The Tender Ship: Governmental Management of Technological Change* (Boston: Birkhauser, 1986).