EM8601: SCIENCE AND THE CITIZEN

The Heart of the Matter

In its final report, the presidential commission charged with examining the explosion of the space shuttle *Challenger* identifies the design flaw that caused the accident and describes in detail the events leading up to the tragedy. It does not describe the underlying causes, within the organization of the National Aeronautics and Space Administration, that made it possible for serious dangers to be ignored. One of the commissioners, Richard P. Feynman of the California Institute of Technology, has addressed this question in a separate document, in which he treats the errors in judgement and execution discovered by the commission as symptoms by which to diagnose larger problems within the space agency. He concludes that NASA's effectiveness in selling its projects to Congress has interfered with its effectiveness as a science and engineering agency.

It is well known by now that the immediate cause of the accident was found to be a faulty seal in one of the joints between sections of the shuttle's right-hand solid-rocket booster. Hot gases eroded a rubber O-ring in the seal and "blew by" it, creating a leak that eventually allowed a plume of flame to escape through the joint and pierce the shuttle's external fuel tank.

The finding came as no surprise. Testimony before the Rogers commission (named for its chairman, William P. Rogers, a former secretary of state) revealed that O-rings in the solid-rocket boosters had been a matter of concern for nearly a decade. Seals are an essential part of the booster, because like all large solid rockets, they are built in sections. There are several reasons for such a design. One is that the fuel is first cast as a liquid, and it might not dry and cure correctly if it were deposited in a single container as large as the shuttle booster. Another reason is that an intact booster rocket would be too large to be transported by rail from the manufacturer to the launch site; because the boosters were made in landlocked Utah, no other means of transportation was available. The particular method of joining the sections that was proposed by the manufacturer, Morton Thiokol, Inc., had been criticized by NASA, however. That was in 1977, when tests first indicated that Thiokol's method of sealing the joints between sections might lead to erosion and leaks.

During the second flight of the space shuttle, in November, 1981, one O-ring in the right-hand solid-rocket booster was eroded, although no gases blew by it. O-rings were eroded during 11 subsequent flights – often in more than one joint – and in nine flights hot gases blew by the "primary" O-ring in at least one joint but did not pass completely through the rest of the seal.

Engineers at Thiokol were alarmed by the unexpected frailty of the seals. In July, 1985, Roger M. Boisjoly, a Thiokol engineer, wrote a memorandum to Robert K. Lund, the vice-president of engineering, "to insure that management is fully aware of the seriousness of the current O-ring erosion problem .... It is my honest and very real fear that if we do not take immediate action to dedicate a team to solve the problem ... we stand in jeopardy of losing a flight along with all the launch pad facilities." A later memorandum, written in October, 1985, by the head of the task force eventually created to solve the problem, begins with the word "HELP!" and ends with "This is a red flag." The engineers' concern came to a head the night before the *Challenger* launch, when, in a teleconference, they tried to convince both the NASA and Thiokol managements not to launch because of the extremely cold temperatures at the launch pad.

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Why were shuttles allowed to fly when critical parts were being damaged in unexpected ways? According to Feynman, managers at NASA and at Thiokol came to regard O-ring erosion as an acceptable risk because O-rings had eroded on previous flights without causing the boosters to fail. Officials noted that in the earlier flights the rings had been eroded by no more than one-third of their radius. Experiments had indicated that an O-ring would have to be eroded by one full radius before it would fail, and so the officials asserted that there was a "safety factor of three." Feynman observes, "This is a strange use of the engineer's term 'safety factor'.... Erosion was a clue that something was wrong. Erosion was not something from which safety can be inferred."

Officials tried to understand the erosion by making a mathematical model, based on data from flights on which the O-rings eroded, to predict the amount of damage to be expected under various conditions. Feynman discusses the way the model was developed and the final form it took and then adds: "There is nothing much so wrong with this as believing the answer! Uncertainties appear everywhere .... The empirical formula was known to be uncertain, for it did not go through the very data points by which it was determined." NASA used this mathematical model to rationalize flying with ever greater risks. Feynman also discusses the design, testing and certification of the shuttle's main liquid-fuel engine and concludes that here too there was a "slow shift toward decreasing safety factor." In these and other cases, subtly, and often with apparently logical arguments, the criteria are altered so that flights may still be certified in time."

To estimate the chances of a space shuttle's failing, NASA managers substituted what they termed "engineering judgement" for the standard methods of probability. They set the probability of failure at about one chance in 100,000. Working engineers thought the chances were closer to one in 100. "If we are to replace standard numerical probability usage with engineering judgment," Feynman asks, "why do we find such an enormous disparity between the management estimate and the judgment of the engineers?"

Feynman hypothesizes that the fundamental cause of NASA's systemic overconfidence was that a major role of NASA management was to get funding from Congress. To do so, he says, they painted too rosy a picture of what could be accomplished with current technology. At a press conference held when he released his independent remarks, Feynman speculated that "by exaggerating what they said they could do, they got in a position where they didn't want to hear too much about the truth .... The *Challenger* mission was the final accident of a sequence of things in which there was warning after warning after warning that something was wrong .... For 10 years they discussed this problem and didn't do anything about it ... because it was hard for information to come up. But we know the information was there at the lowest levels. Why the engineers are at the lowest levels I have no idea, but the guys who know something about what the world is really like are at the lowest levels of these organizations and the ones who know how to influence other people by telling them how the world would be nice ... they're at the top."

Although Feynman judges NASA management more harshly than the official report, the latter does suggest that NASA's original plans for the shuttle were overambitious: the commitment to provide routine and econo-

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mical access to space locked the agency into a schedule too tight to be met with the available resources. For example, the inventory of spare parts was not large enough to accommodate the launch schedule, and so each orbiter was made ready for launch by cannibalizing parts from other orbiters. The commission suggests that NASA's desire to make the shuttle the only major U.S. launch system put too much pressure on the program to meet tight schedules and to be able to handle any payload. NASA's can-do attitude, its willingness to undertake challenging tasks at the last minute, also strained the resources of the ground crews and forced NASA officials to focus on the near term at the expense of long-term safety and economy.

Yet the report does not recommend any major changes in the overall structure of the space program, nor does it hold the highest levels of management responsible for the accident; it reserves its strongest criticism for management at Thiokol and at NASA's Marshall Space Flight Center, the division of NASA responsible for the boosters. The report concludes by urging the Administration and the country to continue supporting NASA.

Feynman's report goes on to draw the connection between the over-optimistic attitude of top management and the accident. He concludes by admonishing NASA to be realistic in estimating costs and setting schedules. "If in this way the Government would not support them, then so be it. NASA owes it to the citizens from whom it asks support to be frank, honest and communicative, so that these citizens can make the wisest decisions for the use of their limited resources." His final remark is that of a physicist who is galled to see what he calls "fantasy" enter the realm of science and engineering: "For a successful technology, reality must take precedence over public relations, for nature cannot be fooled."

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