Experts Ponder Effect of Pressures on Shuttle Blowup

Many claim that decision-making was contaminated by the need to rush ahead, although NASA officials deny it

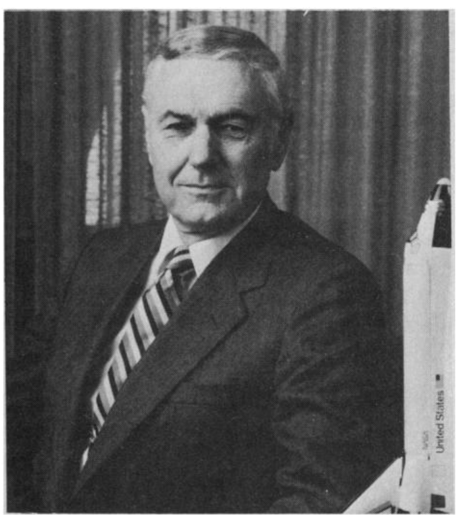
IN several weeks of highly technical and often conflicting testimony before a presidential commission investigating the ill-fated launch of the space shuttle Challenger, one point in particular seems likely to have a lasting impact on the public image of the National Aeronautics and Space Administration. On the eve of the launch, according to four engineers at Morton Thiokol, Inc., one of the agency's major contractors, there was an apparent shift in the agency's philosophy. Previously, they said, the shuttle program managers looked skeptically on the claims of those who believed that a particular flight was ready to go; this time, however, the managers sharply challenged those who sought to hold it up.

Although the NASA officials involved have denied either exerting or feeling any undue pressures, a variety of others—on the commission, on Capitol Hill, and in the agency itself—believe they did. Specifically, internal agency documents leaked to the press indicate that NASA had only one more day to launch the Challenger, before it faced a 13-month delay in a subsequent scientific mission, the launch of a satellite known as Ulysses. Larry Mulloy, a key NASA official, asked "My God, Thiokol, when do you want me to launch, next April?" during prelaunch deliberations about the impact of low temperatures on the booster seals thought to be responsible for the accident.

No one has accused shuttle program officials of knowingly sacrificing safety on the morning of 28 January simply to meet a schedule commitment and to save money. But there is widespread concern that over a long period, budget constraints and schedule pressures have been allowed to exert undue influence on the process of decision-making. Allegations have been made that major shuttle repairs or modifications, which might breach these constraints, were postponed, and that news of potential defects was suppressed, or at least not vigorously sought out by senior managers. According to this view, technical safety requirements were continually shaved so that the program could hew to overly optimistic expectations.

William Graham, the agency's acting administrator, insisted in recent congressional testimony that "NASA's first priority has always been and will continue to be safe and successful shuttle flights." But he also acknowledged concerns that the program had been under severe schedule pressures, and promised "a complete review of the launch rate issue."

One reason the issue has assumed such prominence is a memo dated 4 March to the shuttle program director from John Young, the chief of NASA's astronaut corps. Young wrote bitterly of defects in the seals of the shuttle's booster rockets, and said "there is only one driving reason that such a potentially dangerous system would ever be allowed to fly—launch schedule pressure." Those responsible for safety cannot possibly make it first "when the launch schedule is first . . . no matter what they say," he said.



James Beggs *linked success of shuttle operations to timing of the space station.*

Many believe that launch and schedule pressures have dogged the shuttle since its invention in the late 1960's and early 1970's. Then, on the basis of highly uncertain projections of launch requirements and orbiter performance, the shuttle was sold as a cost-effective replacement for expendable rockets. Its proponents, including James Fletcher, the NASA administrator at the time, claimed that it would consume only $5 billion to $8 billion and fly more than 570 missions during its first 12 years, an ambitious goal that captured the hearts and minds of skeptical congressmen.

Today, it has become clear how optimistic these projections were, with development costs already above $23 billion, and fewer than 150 flights expected by 1994. But the initial idea, that a reusable spacecraft could be cheaply constructed and operated, has nonetheless remained a goal of substantial practical importance. As recently as 1982, for example, the agency successfully persuaded President Reagan to declare that "the first priority of the STS [space shuttle] program is to make the system fully operational and cost-effective in providing routine access to space." According to officials in the Office of Management and Budget and on Capitol Hill, such statements have been sought as a means of reassuring prominent clients, such as the Pentagon, about the program's direction, as well as boosting its prospects in internal and external budget disputes.

"I don't think NASA's been forced to do anything that they didn't want to do themselves," explains Victor Reis, a former space adviser at the Office of Science and Technology Policy. "It has always been their concern to make the shuttle commercially attractive, and to fulfill national policy. This is not to say that these concerns weren't shared by others who added their own pressure, but much of it has been self-imposed."

One reason the agency has been anxious in recent years to cut the cost of the shuttle's flights is increasingly stiff competition from the European Space Agency's Ariane rocket; another is to free additional funds for a space station, which the agency got the President to endorse in 1984. James Beggs, who served as NASA administrator from 1981 until late last year, stated openly that the timing of the space station depends "on how well we can bring the shuttle along and get it operational." Congressional staff aides say that since 1983, the agency has been shifting cash and personnel directly from the shuttle to the station in its formal budget requests.

With between one-half and two-thirds of the shuttle's cost considered fixed, it has long been the agency's position that the best way to achieve needed savings is to increase the flight rate, thereby spreading the expenses over a larger base (see box). As Isaac Gillam, an assistant administrator at NASA for commercial programs, told a Senate subcommittee last year, "the largest single factor in reducing average cost per flight is the ability of [mission planning and launch teams] to support higher flight rates without substantial expansion."

Several years ago, NASA fixed on a "target" launch rate of 24 flights per year by fiscal year 1989, only half of its initial promise, but more than twice its present rate. Few outside the agency thought this number feasible, and the Cabinet Council on Commerce and Trade, a high-level interagency group, concluded last spring that no more than 15 to 18 flights would be accomplished annually. Similar doubts have been expressed by the National Research Council, which noted in 1984 that the agency would have particular trouble supplying enough booster rockets to sustain its most ambitious hopes. "The planning is not in place and procedures remain to be developed to refurbish [the] boosters to meet the mission model," it said, and rated the chance of success as "impossible or highly improbable." But NASA was adamant, according to participants in the interagency deliberations, and successfully inserted the number "24" in a "National Security Launch Strategy" signed by Reagan last February.

The agency has also tried to cut costs by reducing its overhead in Washington. Since 1980, overall employment at headquarters has dropped more than 10 percent, and scientific and engineering employment has dropped 20 percent. The impetus for these cuts came directly from Beggs, a former vice president at General Dynamics who favored a "corporate" system of decentralized management.

One place the cuts have been strongly felt is in the office of NASA's chief engineer, Milton Silveira. The technical staff there has been reduced by one-third over the past few years, and it has suffered additional cutbacks in travel funds. One consequence is that it scaled back reviews of safety, reliability, and quality assurance at NASA's centers from once a year to once every 2 years. Silveira, who did not learn of Thiokol's concerns about the rocket booster seals until after the Challenger accident, says that "a number of us have grumbled that we're too shorthanded to accomplish what we need to be doing. When you're getting more flights going and taking manpower cuts, you're just not going to be able to take as close a look at things." He told *Science* that he considers the accident preventable and that the budget cuts are partly to blame.

A second place where savings have been achieved is in the budget accounts for shuttle modifications and improvements. After only four flights, NASA officially declared the shuttle operational, and began taking funds out of R&D. The budget for rocket booster development, for example, declined from $141 million in fiscal year 1984 to $43 million in fiscal year 1986, and was slated to drop to $11 million next year, and $4 million by 1990. Similarly, a pot of money explicitly set aside in each year's budget for unanticipated problems declined from roughly 10 percent of the program's R&D budget in 1982 to less than 1 percent in 1986. Requested reserves within each separate program, such as booster rockets, also declined from more than 10 percent to less than 4 percent, according to figures provided to *Science* by NASA budget analysts.

The rationale, which everyone considered reasonable at the time, was that as the program matured, it would encounter fewer technical surprises. But several members of the presidential commission, as well as some employees of the agency, believe that the assumptions were too optimistic and the decline too steep. NASA's Aerospace Safety Advisory Board, for example, had recently warned that the program should not be considered operational "in the airline sense, when it clearly isn't," and noted that substantial R&D would be needed through the 1990's. Some critics maintain that in the face of such trends, program managers have had little choice but to overlook a few deficiencies and defer a few repairs.

Much has been made of the fact that in March 1983, for example, shuttle officials explicitly waived a requirement for redundancy on the booster seal suspected as the principal cause of the accident (*Science*, 28 February, p. 909). As NASA disclosed last week, however, it was but one of 740 redundancy waivers granted to the entire shuttle system, of which 114 are on the boosters alone.

Richard Cook, a budget analyst who followed the booster program closely until his departure from the agency last month, says that the scarcity of R&D funds created "a very difficult situation" when the agency finally recognized the seriousness of the seal defects in April 1985. "There were never any funds identified specifically" to fix the seals, he says, so there was little choice but to proceed cautiously. "In my conversations with NASA personnel, it was my understanding that urgency to meet the scheduled shuttle flight rate was the primary motivation for not suspending flights while the repairs were made," he says. Robert Ebeling, a manager of booster assembly at Thiokol, claims that his company was told early on to try improve the assembly of the joints and seals, rather than to modify them, because major changes would require an elaborate and expensive new test program.

Commission member Joseph Sutter, an executive vice president of the Boeing Corporation, believes that "the philosphy was, let's keep her flying, let's work on the changes," but that there was little impetus "to get those changes in the system." According to testimony before the commission, the program's managers apparently knew in June 1982 that a seal in one of the booster rockets was at the limit of its engi-

Flight Rate Pressures

The economics of the space shuttle have been a matter of considerable dispute since the late 1960's, with the National Aeronautics and Space Administration (NASA) on one side, and much of the rest of the government on the other. During deliberations on shuttle pricing last spring, for example, administrator James Beggs claimed that "it would not take an improvement of very much in the efficiency of the shuttle to make it a very, very attractive financial proposition indeed."

Specifically, the agency maintained that at the rate of 24 flights per year, the average cost of flying each mission would be only $84 million. At the rate of 18 flights per year, it said, the cost of each mission would be $97 million. The Congressional Budget Office (CBO) and an interagency group known as the Cabinet Council on Commerce and Trade produced considerably higher estimates, however, noting that historically the shuttle has flown 50 to 70 percent fewer flights than NASA has projected at any given moment. At a rate of 18 flights per year, they said, operational costs would be $98 million to $105 million, while so-called "real" costs—those that included amortized research and development, as well as depreciation—would be at least $186 million. If just 12 flights per year were feasible, the CBO added, the operational costs of each one increased to $126 million, and the real costs to $258 million.

As it turned out, shuttle pricing for the 1989–1991 period was set at a minimum of $74 million per launch, well below actual costs, to give the agency maximum flexibility in beating its European competition. Thus, the agency was to lose millions of dollars each time the shuttle was launched. But it would lose a lot less if the flight rate could be increased (specifically, $106 million less for *each* flight if the rate doubled). Therein, according to the agency's critics, lie the budget and schedule pressures. ■ **R.J.S.**

neering tolerance, but decided to fly the vehicle anyway. "What if [that flight] had been done at a cold temperature? Wouldn't it have maybe taken it over the edge?" Sutter asked. The response, from Allan McDonald, Thiokol's booster program manager, was "I don't know. It is possible. I certainly don't feel good about that."

As recently as last November, Robert Blount, chairman of the Johnson Space Center Payload Safety Panel, decried this "fly as is" philosophy in an internal memo to senior program officials, and concluded that with respect to two upcoming scientific missions with a potentially hazardous radioactive cargo, "schedule pressure is forcing solutions [to problems] which might otherwise be rejected." His remarks troubled the agency's executive board enough for Jesse Moore, NASA's associate administrator for space flight, to write another memo noting that "there is cause for concern" and that "the 'fly as is' decisions on the flight hardware for our first two missions must be monitored very closely." Moore noted pointedly, however, that "the wagon is loaded."

With respect to the Challenger, no one disputes that the decision to launch was made in the presence of considerable technical uncertainty. As Mulloy has testified, "We did not conclude on that night that the primary would not function and seal. That was inconclusive." Some uncertainty is normal, of course. The question that the commission is presently trying to address is whether the uncertainties that day were unusually great, and if so, why a decision was made to proceed.

According to testimony, Thiokol's initial judgment—that defects in the seals rendered any launch below 53° unsafe—raised concerns in part because cooler temperatures are common not only in Florida but also at a launch site in California, potentially forcing a major disruption of the existing schedule. Thiokol's senior vice president Jerry Mason suggested that the company's recommendation was changed in part because of an unwillingness to be the skunk at a garden party. "From a schedule standpoint, we take a lot of pride in the fact that we have supported all of the launches to date, and if there was any pressure, we wanted to continue to do the job we had been doing," he said. "And that kind of situation exists every time. We have to say, are we ready to fly or not, and we want to be ready to fly."

Criticism of these pressures is hardly new. In 1978, Herbert Grier, the chairman of NASA's safety advisory board, told a congressional committee that "we feel one of the important safety considerations is the effect of the schedule driving technical people to make 'fixes' rather than engineer a solution to the problem." In January 1983, the board noted that "the pressure of schedule seems to relax the rigor" of safety certifications, and a year later, it criticized NASA's management for "a continuing strong bias" in this direction.

According to a senior NASA engineer who specializes in rocket boosters, over time the pressures contributed to a reluctance by lower echelon officials to raise concerns that would have the effect of disrupting settled plans. There was "a tendency to treat repair problems as bad news, and a pronounced reluctance to bring bad news to higher levels," he says. Last autumn, for example, a senior scientist at Thiokol wrote several memos to his company's senior engineer suggesting a prompt effort to repair seal defects. Although one memo warned explicitly of the danger of "a catastrophe of the highest order—loss of human life" and another suggested that future flights be postponed until the repairs were made, the depth of this concern was never conveyed by the company to rocket program managers at the Marshall Space Flight Center. Similar safety concerns, expressed by Rockwell International, the chief shuttle contractor, on the day of the Challenger's launch also got watered down as they traveled through the corporate hierarchy.

Key facts were somehow not circulated to the right people. Allan McDonald, who has been with Thiokol for 26 years and chairs a senior review board for the boosters, said that he only recently became aware that a redundancy requirement in the seals had been waived. "I was a bit shocked by that,"

NASA Faces Budget Crunch

Recovering from the loss of the space shuttle Challenger will place the National Aeronautics and Space Administration (NASA) under a severe financial strain even if the agency does not ask for a replacement shuttle, according to a new analysis by the Congressional Budget Office.*

Based on NASA's own figures, the budget office estimates that the agency will need an extra $142.5 million this year, and another $115 million over its fiscal year 1987 budget request, just to deal with the costs of the accident and its aftermath. Extending the estimates for several years beyond that, the budget office finds a total net cost of $463 million—but only when the actual costs are offset by such "savings" as not having to operate the Hubble Space Telescope, the Galileo and Ulysses spacecraft, or any of the other science and applications missions that are currently grounded.

However, the budget office also emphasizes that these numbers are very preliminary and probably on the low side. Under the category of "reconstitution" costs, for example, NASA estimates $341 million for the expenses involved in the accident investigation plus the replacement of equipment lost in the accident (other than the orbiter itself), and some $350 million for any shuttle system modifications suggested by the investigation. But the investigation is not over. Moreover, the budget office points out that modifying the shuttle solid rocket booster alone will cost more than $200 million. NASA is also reviewing an additional 2300 critical items at the direction of the presidential commission investigating the Challenger accident. If only a few of these items require substantial redesign, says the budget office, the total cost of the modifications could easily rise much higher than $350 million.

Given the general determination in Washington to reduce the size of the federal deficit, this money may have to come out of existing NASA programs. The budget office points to the space station project, for example, which could be slowed down. Or cuts could be made in space science and applications, since missions in this category will have to be delayed anyway.

These measures would be painful, and the report states specificially that the budget office is not advocating them. But by taking such measures the added costs could be accommodated within the existing NASA budget. A $2.4-billion replacement orbiter, however, is a different story. While the budget office did not look at this issue in detail, the report does estimate that providing NASA with a new orbiter, while keeping the space station on track and continuing with a full range of space science and applications, would require an increase in the agency's budget of $1 billion a year until 1990. Thus, unless NASA is exempted from efforts to cut the federal deficit—a prospect considered highly unlikely in Washington—something is going to have to give. ■ M. MITCHELL WALDROP

* "Budget Effects of the Challenger Accident," Congressional Budget Office, March 1986.

he told the commission. "I kind of thought I was one of the top people working on the program, and I didn't know about that until August of '85." Roger Boisjoly, the firm's senior seal engineer, was unaware on the eve of the launch that water had gotten into rocket joints in the past, and neither he nor anyone else considered the possibility that the seals had been broken by ice.

The agency's standard procedure, according to NASA officials, was to try to resolve most disputes at lower levels and pass only the results along to senior officials, not the flavor of the debate. Stanley Reinartz, a senior official at Marshall, testified that he decided not to tell his superiors about Thiokol's anxieties early on because he "felt it was necessary to get a full understanding of the situation" and later, because the concern "was worked and dispositioned with full agreement among all responsible parties" at his level. "That is the normal course of our operating mode within the center," he said, adding that, in retrospect, this may have been a mistake.

Richard Truly, the new shuttle program director, has promised that "we will not launch again until safety-related issues have been properly addressed throughout the total NASA system." But this will require a lot of money and a measure of patience that Congress and the shuttle's clients may be unwilling to provide. According to the memo from astronaut corps director John Young, not only the boosters but also the external tank, the fuel cells, the landing gear, various engine valves, the auxiliary power units, the computer software, and some satellite motors may need modification to eliminate safety hazards. New weather-related launch criteria will have to be drawn up.

"Flight safety . . . has to have real teeth in it," Young says. "It will not be free." Graham recently put the cost of repairs at $350 million, and the cost of a replacement shuttle at $2.8 billion. Meanwhile, the agency has decided to assist in the development of new expendable rockets, which will ultimately weaken further the shuttle's already shaky economic base.

Many of the agency's traditional supporters believe that if the program is to be maintained at a reasonable level, it should no longer be a slave to cost-accounting standards. With increasing urgency, they argue that the shuttle, as a high-risk technological venture of considerable symbolic importance, should be freed, once and for all, from the illusion that it makes economic sense, as well from the accompanying economic and schedule constraints. Though the argument has a peculiar logic to it, in the year of Gramm-Rudman it might not get very far. ■ **R. JEFFREY SMITH**

NAE Elects New Members

The National Academy of Engineering has elected 73 new members and six foreign associates. This brings the total U.S. membership to 1289 and the foreign associates total to 113. The new members are as follows:

William F. Allen, Jr., Stone & Webster Engineering Corp.; **David Atlas,** University of Maryland, College Park; **James E. Bailey,** California Institute of Technology; **David P. Billington,** Princeton University; **Harvey K. Bowen,** Massachusetts Institute of Technology; **Walter L. Brown,** AT&T Bell Laboratories, Murray Hill; **John F. Cashen,** Northrop Advanced Systems Division, Pico Rivera, CA; **Robert P. Clagett,** AT&T Technologies, Inc., Princeton; **Richard R. Conway,** Union Carbide Corp.; **Robert H. Curtin,** De Leuw Cather/Parsons, Washington, DC.

Morton M. Denn, University of California, Berkeley; **Lester F. Eastman,** Cornell University; **Edward A. Feigenbaum,** Stanford University; **John W. Fisher,** Lehigh University; **John A. Focht, Jr.,** McClelland Engineers, Inc., Houston; **John K. Galt,** Sandia National Laboratories; **L. M. Holm,** Union Oil Co. of California, Brea; **Lee A. Iacocca,** Chrysler Corp.; **James D. Idol, Jr.,** Ashland Chemical Co., Columbus; **Anthony J. Iorillo,** Hughes Aircraft Co., El Segundo.

Robert B. Jansen, Spokane, WA; **Edward G. Jefferson,** E. I. du Pont de Nemours and Co.; **Thomas V. Jones,** Northrop Corp., Los Angeles; **Angel G. Jordan,** Carnegie-Mellon University; **Albert S. Kobayashi,** University of Washington, Seattle; **Joseph T. Kummer,** Ford Motor Co.; **Kaye D. Lathrop,** Stanford University; **Yuen-Tze Lo,** University of Illinois, Urbana; **Arthur Lubinski,** consultant, Tulsa, OK; **Chiang C. Mei,** Massachusetts Institute of Technology.

Harold Mirels, Aerospace Corp., Los Angeles; **Joseph B. Moore,** United Technologies Corp., West Palm Beach; **Richard M. Morrow,** Amoco Corp., Chicago; **Joel Moses,** Massachusetts Institute of Technology; **Toshio Mura,** Northwestern University; **Gerald Nadler,** University of Southern California, Los Angeles; **George L. Nemhauser,** Georgia Institute of Technology; **Jack N. Nielsen,** NASA Ames Research Center, Moffett Field, CA; **William G. Oldham,** University of California, Berkeley; **Morton B. Panish,** AT&T Bell Laboratories, Murray Hill.

Jacques I. Pankove, RCA Laboratories, Princeton; **Robert H. Park,** Fast Load Control, Inc., Freeport, IL; **John R. Paulling,** University of California, Berkeley; **Emil Pfender,** University of Minnesota, Minneapolis; **Robert Plonsey,** Duke University; **John W. Poduska, Sr.,** Apollo Computer Inc., Chelmsford, MA; **Michael Prats,** Shell Development Co., Houston; **Ronald W. Pulling,** Tippetts-Abbett-McCarthy-Stratton, Washington, DC; **Rowland W. Redington,** General Electric Research and Development Center, Schenectady; **Jerome G. Rivard,** Ford Motor Co.; **Chih-Tang Sah,** University of Illinois, Urbana.

Eugene C. Sakshaug, consulting engineer, Lanesboro, MA; **George A. Samara,** Sandia National Laboratories; **Charles D. Scott,** Oak Ridge National Laboratory; **Herbert J. Shaw,** Stanford University; **William H. Silcox,** Standard Oil Co. of California; **Merrill I. Skolnik,** Naval Research Laboratory, Washington, DC; **Ernest T. Smerdon,** University of Texas, Austin; **Ephraim M. Sparrow,** University of Minnesota, Minneapolis; **Dale F. Stein,** Michigan Technological University, Houghton; **Kenneth N. Stevens,** Massachusetts Institute of Technology; **Chung L. Tang,** Cornell University.

Gerald F. Tape, consultant, Bethesda, MD; **Paul E. Torgersen,** Virginia Polytechnic Institute and State University, Blacksburg; **Alexander R. Troiano,** Case Western Reserve University; **Arthur F. Veinott, Jr.,** Stanford University; **Daniel I. C. Wang,** Massachusetts Institute of Technology; **Max T. Weiss,** Aerospace Corp., Los Angeles; **Harold A. Wheeler,** Hazeltine Corp., Greenlawn, NY; **Eugene C. Whitney,** consultant, Pittsburgh, PA; **Sam B. Williams,** Williams International Corp., Walled Lake, MI; **John J. Wise,** Mobil Research and Development Corp., Paulsboro, NJ; **Alden P. Yates,** Bechtel Group, Inc., San Francisco.

The new foreign associates are:

John Argyris, Institute of Astronautical Structures, University of Stuttgart, Federal Republic of Germany; **Donald A. Chisholm,** Northern Telecom Ltd., Mississauga, Ontario, Canada; **Arthur C. Clarke,** University of Moratuwa, Colombo, Sri Lanka; **Bacharuddin J. Habibie,** minister of state for research and technology, Republic of Indonesia, Jakarta; **Anthony Kelly,** University of Surrey, Guildford, Surrey, U.K.; **Yasua Mori,** University of Electro-Communications, Chofugaoka, Chofu City, Tokyo, Japan.