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Case Studies in NASA High-Technology Risk Assessment and Management

by

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This study discusses the approach of NASA managers in the assessment of risk in three critical decisions: the Apollo 8 decision to orbit the Moon in 1968, the servicing of the Hubble Space Telescope in 1993, and the privitization of the Space Shuttle in the latter 1990s.

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Table of Contents

APOLLO 8: THE DECISION TO ORBIT THE MOON

by

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On Christmas Eve, 1968, three astronauts read from the Book of Genesis while they circled the moon. They had recently seen the moon, and also been the first human beings to witness an earthrise, as the blue planet emerged above the moon's horizon. The astronauts had been to the dark side of the moon, out of contact with earth, and would soon repeat that experience as they orbited the lunar surface. They wanted to communicate their observations to the people of earth and wish the millions who listened 250,000 miles away a merry Christmas. When they splashed down in the ocean and were picked up safe and sound, people everywhere, but especially in America, rejoiced. It had been a terrible year for the United States. Robert Kennedy and Martin Luther King were assassinated, the Viet Nam War took a dramatic turn for the worse, a president was driven from office, and civil rights and anti-war protesters took to the streets and set fires in Washington and other cities.

The first voyage to the moon, at the very end of the year, raised hopes and displayed the best of which the United States was capable. It was a special moment in a time of trouble. *Time* magazine, which had intended "the dissenter" as its "Man of the Year," replaced him with the three Apollo 8 astronauts.

For NASA, Apollo 8 proved that the decision President John Kennedy had made in 1961 had a good chance of being realized. It also relieved much of the burden of the 1967 Apollo Fire, which had killed three astronauts and cast doubts on the agency's technical capacity. It gave renewed confidence

and impetus to a beleaguered agency and nation. Six and one-half months later, Neil Armstrong stepped foot on the moon, thereby fulfilling the goal Kennedy declared in 1961.

In the history of the Apollo program, three missions stand out above all the rest. They are: Apollo 11, the moon-landing flight; Apollo 13, the flight that almost resulted in tragedy, but which was turned instead into a remarkable example of human courage and organizational teamwork; and Apollo 8, the first manned voyage to and around the moon.

What is not well known is that Apollo 8 was a flight that was improvised, whose success accelerated NASA's voyage to the moon, and which was an exceptionally high-risk venture. Many in NASA as well as outside observers of the agency would later look back on Apollo 8 "as the boldest decision NASA ever made."[1] It would be called "the single greatest gamble in space flight then, and since."[2] It was also termed an unusually well considered decision, "carefully assessed" with "great precision" by many participants, risky but "prudent."[3]

In hindsight, Apollo 8 was one of the most important decisions in NASA's history, one of the clearest examples of risk management. From the time the decision was first conceived to the time it was implemented, the issue of technical risk was foremost in the minds of NASA officials and astronauts. So were the political risks of failure.

TECHNICAL AND POLITICAL RISKS

Technical risk pertains to the failure of hardware, software, and astronaut-machine interface that makes accomplishment possible. Political risk refers to the impacts of technical failure on the fortunes of NASA and its officials. Political risk also involves the hazards of appearing inactive or not making progress. Technical and political risks are intertwined, inseparable in the decision-making process, affecting the nature of the decision, its timing, and communication to the larger public.

What factors led to the Apollo 8 decision? Who was Apollo 8's champion? Who was for it -- or against it? Was the decision altered as it moved toward acceptance? Why? How were political risks

factored in, by whom? When? With what consequence for the decision? All these questions are critical in understanding the dynamics of the Apollo 8 decision-making process.

BACKGROUND AND SETTING

In the first half of 1967, NASA's drive to the moon was delayed by the Apollo fire, which took the lives of three astronauts. Following an investigation of NASA and North American, NASA's prime contractor on the Apollo spacecraft, NASA began a difficult period of recovery, making changes in organization, personnel, and equipment. This period began in November with the launch of the first Saturn rocket, itself a demonstration of the wisdom of the "all-up" decision made in 1963 by Manned Space Flight director George Mueller. All-up was a high-risk decision that meant omitting certain incremental tests of components in favor of a test of the fully assembled rocket, flying and testing equipment all at once. This all-up decision was considered extremely risky by the German rocket engineers under Wernher von Braun, whose approach was slower and more cautious. Mueller's view prevailed as the only way to keep the Apollo program on schedule with its lunar-goal timetable. Mueller regarded the risks as acceptable and his superiors in NASA backed him.[4]

However, the sense of achievement in November was rudely interrupted 4 April 1968 when the second Saturn test suffered a violent up and down shaking, a "pogo" effect. Had the flight been manned, which it was not, the crew would have aborted the flight, if they had survived at all. Fortunately for NASA, few outside the agency took note of Saturn's troubles, as the country was preoccupied with the shooting of Martin Luther King, which occurred at the same time.[5]

NASA, however, was worried and immediately launched an internal investigation. Meanwhile, another problem became visible. The Lunar Excursion Module (LEM), the spidery machine that would ferry two astronauts to the lunar surface from an orbiting mother ship, was falling behind schedule. Also, word came to NASA from the intelligence agencies that the Soviet space program was picking up speed, and might be attempting a manned flight to the moon by the end of 1968. The Russians did not have the

capability to land on the moon, but might be able to send a spaceship to the moon and around it in a figure-eight pattern, making use of the moon's own gravity to return the ship to earth.[6] All these concerns, real and possible, converged in the summer of 1968, when one man decided to act.

THE INITIAL PROTAGONIST

George Low exemplified the kind of technical manager who was fully engaged in the Apollo mission. He had been placed in charge of redesigning the Apollo spacecraft (command module and service module) in the management shake-up after the fire. A native of Austria, 42 years old, a long-time NACA and NASA employee, Low was a brilliant engineer and manager who worked tirelessly to get Apollo's spacecraft ready for a flight to the moon. He had been an official in Headquarters and had served as Deputy Director of the Manned Spacecraft Center prior to his present assignment. That he was given the critical task of managing spacecraft redesign showed the respect top NASA officials had for Low's skills.

In July, convinced that the Apollo spacecraft was now ready for the moon mission, Low took a much needed vacation. While away, however, he could not take his mind off the space program. He had heard that von Braun's rocket team at the Marshall Space Flight Center had diagnosed Saturn's pogo problem and was working on its remedy. LEM was another matter. It would be months late. The next flight, Apollo 7, was scheduled as the first manned Apollo flight. In earth orbit, it would take place by early October and test the improved Apollo spacecraft. After that flight would come Apollo 8, another manned flight in earth orbit, this one testing the LEM. It was scheduled for December. Now this flight would be indefinitely delayed. With the delay, the Apollo goal to land a man on the moon "before this decade is out" would be in jeopardy.

When Low returned to Houston at the beginning of August, he had conceived a possible solution to the problem. Assuming the spacecraft and rocket were ready, why not fly men to the moon without LEM? The men would not land, but loop around the moon and come back. Not only would NASA not

fall behind schedule, but it would gain experience in lunar flight sooner than planned. This solution was bold to say the least, for it meant going as early as possible to the moon on the first manned voyage of a Saturn 5 rocket.[7]

ENLISTING ALLIES

The first man with whom Low shared his idea was Christopher Kraft. Kraft was Director of Flight Operations at Houston, a veteran of NACA/NASA, and, like Low, very highly regarded within the agency. When he heard Low broach the subject of a new, more ambitious Apollo 8 mission, Kraft was initially stunned. Low said he "was pretty sure of the spacecraft and its hardware." He wanted to know if Chris was "ready with his operational people." "Did we have the trajectories and [computer] programs," he asked.

Kraft conferred with his specialists and came back to Low at the beginning of the workday August 9. As Kraft recalled:

> This was way ahead of the schedule that we had intended to build some of the software necessary to do the job in the control center. We had to develop all the procedures, all the mathematics. At the same time, Lunar Orbiter [an unmanned probe of the moon] had shown us that the determination of orbits around the moon was not going to be a very easy problem.

Nevertheless, Kraft said his team of navigation/flight control people could do the job.

Moreover, Kraft had himself come to believe that Apollo 8 should go beyond the "loop-around" flight to an even more demanding lunar orbit flight. He told Low such a mission was not only possible, but desirable. "It would give us an early lead" in developing the experience essential "to fly the landing missions." Kraft thus advocated a modification in Low's proposal that added benefits to the lunar journey -- at the cost of additional risks.[8]

Low went immediately to the office of Robert Gilruth, the Center's Director, and explained the new options being considered. Gilruth called in Kraft and also Deke Slayton, chief of the astronaut

office. Slayton had already been told of the new mission, and was supportive. After listening to the three visitors, Gilruth agreed to the lunar orbit proposal. "It took me ten seconds to respond," he recollected.[9]

What about the Saturn rocket? Would it be ready? What would Headquarters say? Others in NASA? Low and Gilruth got on the telephones to see if a meeting could be arranged to discuss the ideas and possible issues. General Sam Phillips, director of the Apollo Program in Washington, was contacted. He was intrigued and suggested that relevant parties meet that afternoon in von Braun's office at Huntsville, Alabama.

At 2:45 p.m., a meeting took place in Huntsville. Present were Phillips, von Braun, Gilruth, Kurt Debus (director of the Kennedy Space Center), and various other key officials including Low, Kraft, and Slayton. Low set the tone for the meeting, warning that the only way NASA could meet its lunar-landing deadline would be by flying men to the moon in Apollo 8, at the end of the year. Von Braun answered the vital question about the Saturn 5 rocket by saying it would be ready. "We didn't feel too concerned about the launch vehicle risk," because:

> we all felt we were on top of the Apollo 6 [pogo] problems... From our point of view, the risk difference between a Saturn 5 launch to earth orbit and to go from there on to the moon was a relatively small thing.

He said at the meeting, "It doesn't matter to the launch vehicle how far we go."[10]

Debus declared that the Kennedy facility could be prepared for a launch in December. Others added their views, Phillips mainly listening . The record of the meeting does not mention the competition of the Russians. However, it was certainly a consideration of those present. According to Kraft: "Everybody wanted to beat the Russians' ass." Astronaut Buzz Aldrin calls competition a reason for going beyond the lunar fly-by to the "more ambitious - and considerably riskier -- lunar orbit mission."[11] It was in the context of Soviet competition that Frank Borman, the astronaut asked to lead the mission, was informed. Borman was called to Slayton's office on August 10, one day after the Huntsville meeting. Asking Borman to close the door behind him as he entered his office, Slayton told him that intelligence sources believed

> ...that the Russians are planning a lunar fly-by before the end of the year. We want to change Apollo 8 from an earth orbital to a lunar orbital flight. I know that doesn't give us much time, so I have to ask you: Do you want to do it or not?

Borman did not hesitate: "Yes."[12]

THE DECISION TO PROCEED

What had begun with one man -- Low -- was now a coalition of advocates. An important convert was Phillips, who had decided shortly after the Huntsville meeting that he would support the Apollo 8 lunar orbit decision. He could see the technical risks as well as the benefits. An engineer and Air Force general, Phillips had managed the huge Minuteman missile program, and was used to high stakes involving big money and human lives. Later, he would write down for his superiors the pros and cons of the lunar orbit choice, and state that the risks were acceptable as far as he was concerned. At this point, however, his superiors did not know about the gathering force below them in NASA.

The three men who had to be convinced if Apollo 8 was to launch in December were George Mueller, Director of the Office of Manned Space Flight; Tom Paine, Deputy Administrator; and James Webb, Administrator. Mueller and Webb were in Europe attending a conference. Hence, the first of the three who could be approached was Paine. New to NASA, Paine had come in early 1968 from General Electric. He was a metallurgical engineer known as an imaginative and big thinker.

A meeting was arranged at NASA Headquarters August 13. Phillips led a delegation of officials from the centers. All favored going ahead with the lunar orbit mission. Again, Low was direct and to the point: "Assuming Apollo 7 is a success there is no other choice." Noting the problems Apollo 6 had had, Paine reminded the gathering that NASA had been recently debating whether it was safe even to put men on a Saturn 5 rocket. "Now you want to up the ante," he remarked. Directing his question to Phillips, he asked, "Do you really want to do this, Sam?" Phillips responded that he did. There was more discussion, and at the end Paine said he was aboard, but "We'll have a hell of a time selling it to Mueller and Webb."[13]

Phillips now telephoned his immediate superior, Mueller. Mueller was "skeptical and cool" to the idea. He saw significant risks and uncertain gains. He said he'd think about the proposal further. Hearing nothing back for two days, Phillips and Paine reached Webb. They found he had not been briefed by Mueller on the earlier call. When they explained the lunar orbit proposal to him, NASA's Administrator was dumbfounded. "If a person's shock could be transmitted over the telephone, I'd probably have been shot in the head," recalled Phillips.

Paine tried to reassure Webb that the plan had been thoroughly discussed and all NASA's top technical people believed the lunar orbit mission was viable. A lawyer and administrator, Webb generally did not second-guess his associates on technical judgments. However, he regarded himself as the expert on political aspects of decisions. He saw immense political risks in the decision. At first inclined to say no, he ended by asking Paine to send him further information, in writing.[14]

By the end of the day, this information was on its way. Paine's seven-page cable outlined the rationale for a lunar-orbit flight, pending success in the earth-orbit flight of Apollo 7. If it turned out that the lunar flight was deemed inadvisable, the astronauts could fly another earth-orbit flight in December. Without the LEM, however, such a flight would gain little beyond Apollo 7. Webb discussed the matter with Mueller and the next day, August 16, called Paine. He directed him "to plan for the lunar orbit flight but to make no public statement about it." He "asked Paine to notify the White House and the President's science advisers about any drastic changes in mission planning.[15]

This was not a final decision, but it was the essential enabling decision that Webb's associates had to have to move forward. The next day Phillips went to Houston and conferred with Gilruth, Low, Kraft, and Slayton. He said he had "clear authority" from Webb for NASA to prepare for an Apollo 8 launch in December. NASA should "speak of the flight as earth orbit while continuing to plan for a lunar orbit." The time to start training the Borman crew was now.[16]

On August 19, "NASA publicly announced the [Apollo 8] flight as an expansion of Apollo 7, although the agency spokesman said that the exact content of the mission had not been decided."[17]

PREPARATIONS BEGIN

August 19 was also the day when Kraft and Borman, along with various technical specialists, met in Houston to outline the first flight plan to the moon. The plan had to balance maximum technical gains with maximum safety for the astronauts, not a simple process. Kraft and Borman were unique individuals, and held one another in great respect. "Kraft was absolutely unflappable in a crisis," recalled Borman, "and he shared with Gilruth a determination never to let any man or woman in the program neglect what they considered to have as high a priority as the mission itself: the astronauts' safety."[18] Borman was one of the most highly esteemed astronauts, not only brave, but quite intelligent. He had been selected to serve on the Apollo fire investigation board and had taken a lead role among the astronauts in the recovery effort that followed. His being selected as commander of Apollo 8 reflected the agency's confidence in his ability.

Kraft and Borman decided on a six-day mission, to commence December 21. This would permit Apollo 8 to arrive at the moon when the sun was rising across the Sea of Tranquility, allowing the crew to scan this area as a potential landing site. Getting to and from such a vantage point entailed a number of decisions where the flight plan could be modified in the interest of safety. For his part, Borman decided to argue strongly on the side of minimizing risk. As he recalled: "I wasn't that pessimistic but I damned well knew the risks, and from the very beginning I wanted to increase the odds in our favor."[19]

The first critical decision point would occur shortly after launch, when Apollo 8 had achieved earth orbit. All the manifold systems would be checked and rechecked by the astronauts in space and controllers at Houston. If anything went wrong, or did not look just right, a decision to stay in earth orbit for a ten-day mission could be made. If the crew and flight controllers agreed that all was well, the astronauts would perform a 'burn" of the engine and lift out of orbit toward the moon. This decision point was called Trans-Lunar Injection (TLI).

The spaceship could almost automatically fly around the moon and back toward the earth, tracing a figure-eight pattern, thanks to laws of celestial mechanics and small maneuvering thrusters astronauts could use as necessary. That was the trajectory of least risk. The decision had already been made to go into orbit if possible; hence, the next major decision point occurred when the astronauts reached the moon. Assuming all was well, the men would fire their rocket engine in such a way as to go into lunar orbit, an action called Lunar Orbit Insertion (LOI).

What Kraft and Borman had to decide now was how long to stay in orbit. Some of the technical experts attending the meeting urged as many orbits as possible in order to augment data-gathering, especially about mass concentrations of geological formations on the moon that could affect orbit and landing. As far as Borman was concerned, the fewer orbits the better. Kraft worked out a compromise that made for 10 orbits, or a total of 20 hours circling the moon.

The next decision point was that to leave the moon -- called Trans-Earth Injection (TEI). This was considered the riskiest part of the flight. The rocket that would be fired, called the Service Propulsion System (SPS), had to work. There was no back-up, since there was no LEM. Earlier safety reviews of lunar flight requirements had always listed the LEM as a potential "lifeboat," because its powerful engine (to descend to, and ascend from the moon) could be used in other ways in an emergency. It could propel the spacecraft from lunar orbit to a return trajectory to earth, should SPS fail.[20] The LEM would in fact become a lifeboat in Apollo 13, as millions of people saw in the film based on this flight. In 1968 it would not be available.

Assuming SPS worked, Apollo 8 would be on its way back to earth, and the last high-risk decision point would come in the final hour of its journey. The crew would have to position their craft for reentry at the right speed and at the right angle, lest their spacecraft burn up in the atmosphere or bounce off into space. The speed (25,000 miles per hour) and angle (2 degrees) were unprecedented.

There was another problem, Borman was told. He and his crew would be landing at night, and that might complicate rescue a bit. Borman's view was that a night landing, after all the other risks that

would have been faced up to this point, was not worth his worrying. Finally, Borman raised the issue of why he had to take a television camera aboard on the trip -- it added unnecessary weight. He was told that dispensing with the camera was not an option. The weight was trivial and not a safety factor. The NASA policy was to let the world share in as much of the Apollo 8 experience as possible.[21]

The flight plan was now essentially complete. Higher levels of the agency would go over it and determine whether it should have their endorsement or not. Meanwhile, the astronauts commenced arduous training. In addition to Borman, the crew included James Lovell and William Anders. Lovell's job was to handle navigation, while Anders specialized in science, monitoring equipment and photographing the moon. As Commander, Borman was the generalist, with cross-cutting responsibilities.

Each was a former test pilot, knew the risks, and accepted them for different reasons. For Borman, Apollo was like a war, and he wanted to see the US the winner. Lovell saw Apollo 8 as "worth the risk for the adventure alone, never mind the potential for scientific discovery." Anders, more than the others, calculated the pros and cons. He "did not worry that much about himself. He did worry about his family." The pluses for him were at least three: adventure, duty to country, and the chance to make history. "If he had two chances in three of coming back -- and he figured the odds were probably a good bit better than that -- he was ready."[22]

PROVIDING POLITICAL COVER

By September, NASA was well on its way to a Christmas rendezvous with the moon. There had still been no public announcement of the new plan for Apollo 8, in line with Webb's directive. The NASA Administrator, concerned about the political risks, wanted to keep his options open and reveal NASA's intent in his own way to the President and Congress. When he spoke with President Johnson, he declared "it was time for America to gamble," that a lunar-orbit flight would "provide valuable knowledge about navigation to and around the moon, perhaps hasten a lunar landing." Johnson told him "he would support whatever final decision NASA made."[23]

Webb no doubt also spoke with senior legislators concerned with space. It was his style to hold the initiative in dealing with his political overseers, keeping them informed but doing so with a certain artfulness by which he protected NASA's autonomy. He always wanted NASA to make the hard technical choices, including those involving technical risk. He may well also have made use of reports concerning Soviet intent with respect to a lunar fly-by. On September 14, the Soviets obliged NASA by sending an unmanned probe, called Zond, around the moon and back. Webb certainly believed the US was in a real race, and would have conveyed this sense to both the President and Congress. In view of the criticism NASA had received after the Apollo fire, Webb had to inform his elected superiors of the risk NASA was taking, but he did so in his own way, pointing out the rewards, and providing political cover for his agency's technical decision.

On September 16, to the surprise of everyone, Webb suddenly announced he was leaving NASA, effective October 7. Webb's leaving was strategic on his part, an effort to control the choice of leadership at NASA after he and President Johnson were gone. He felt that the new president, expected to be Richard Nixon, would make major changes at NASA if Webb were still around in January. Even if Hubert Humphrey won, he would want to replace Webb with a man the new president felt was loyal to him.

Webb believed that if he left early, before the November election, he would thereby give his deputy, Tom Paine, perceived as an apolitical technocrat, a chance to prove his mettle. In that event, the new president might be willing to keep Paine and make no changes in NASA until after the lunar-landing flight. At this point in time, Webb's mind was totally focused on NASA's achieving the Kennedy goal, even if he was not there at the finish line. Also, he believed that if there were a mishap on a flight prior to the lunar landing, he could fight more strenuously for the space program from outside than inside the agency. The transition strategy, which Webb conveyed to Johnson on September 16, made so much sense to the president that he accepted it on the spot and directed Webb to announce his leaving immediately, rather than waiting an unspecified time as Webb had intended. In the speculation that

followed, one theory was that Webb had suffered a failure of nerve due to Apollo 8's riskiness. There is nothing in Webb's behavior as NASA Administrator to suggest any credibility to this theory. Rather, his consistent approach was to protect his organization and the Apollo goal. He used his political skills to sell NASA's technical judgments to his Washington masters.[24]

THE DECISION TO LAUNCH

When the time for a final choice on Apollo 8 came, it would be Paine who would make the decision. For Low, this meant that a lunar-orbit flight was certain, since Paine earlier had been an advocate to Webb.[25] Now that Paine was the decision-maker, however, and had the ultimate responsibility, he was not so sure the decision was a foregone conclusion. As Acting Administrator, he wanted to make sure all the risks and benefits of a lunar-orbit flight were carefully reviewed. Also, his top associate in manned space flight, Mueller, was by no means sold on the merits of Apollo 8 at this time.

Absolutely critical to the final decision, everyone knew, was Apollo 7, the first manned flight in a spacecraft that had been redesigned substantially following the Apollo fire. On October 11, using a smaller Saturn rocket than the Saturn 5, Apollo 7 was launched into earth orbit. Eleven days later it splashed down in the Pacific, a complete success.

The stage was now set. The media was by now fully alert to the fact that a lunar flight might be next, although NASA still insisted that the final decision remained to be made. Paine said he wanted a thorough evaluation of the risks involved before deciding. Mueller took the lead in most of the reviews. Exactly where Mueller stood was not always clear. He would later insist that he was playing the devil's advocate role, and there is no question that he was a force to counter the momentum in favor of going ahead. As the protagonist in the "all-up" decision that had accelerated testing of Saturn, Mueller was certainly a man who had established his credentials as a risk-taker.

However, he had been through the chastening experience of the Apollo fire, and was not about to take unnecessary risks, and he regarded the lunar-orbit flight as not worth the risks. At least, that was the view he conveyed in the summer and fall of 1968. Robert Sherrod, an astute journalist documenting the Apollo program at this time, recalled Mueller telling him on September 24: "What can we accomplish in it? If we could clearly advance our knowledge, I'd be more enthusiastic." Mueller badgered the proponents of the decision to answer one challenge after another concerning the flight, especially exasperating Low, who did not care for Mueller in any event. By the beginning of November, Apollo 8 was still only "50-50" in Mueller's mind.[26]

On November 4 Mueller wrote Gilruth, asking Houston to take another look. He stated, "there are grave risks to the program as a whole, not just to the Apollo 8 mission." He was satisfied that the technical risks were reasonable and acceptable and "the greatest single advantage of flying Apollo to the moon was the way it galvanized people." "Yet," Mueller explained, "you and I know that if failure comes, the reaction will be that anyone should have known better than to undertake such a trip at this point in time." Sherrod expressed Mueller's position as "a curious mixture of boldness and timidity." Mueller believed more flights could mean more risks, not less. Rather than spreading out the risks, taking smaller ones more often, he felt it was better to concentrate them on fewer flights. This position caused him to oppose any flight he thought was not absolutely necessary.[27]

Low believed an Apollo 8 flight to the moon was essential to realizing the ultimate goal. Who was right and who was wrong? The answer came down to professional judgment. As the reviews continued, more and more professional judgments converged around a go decision. On November 10 Mueller convened a meeting of Apollo contractor executives and virtually all of them said NASA should fly to the moon on Apollo 8. "This is what we came to the party for," quipped Leland Atwood, president of North American.[28] If NASA needed another spur to decision, this came the same day, when the Soviet Union launched another Zond to the moon and announced its purpose was to perfect an approach that could be used by a manned craft.[29]

November 11 was a holiday in government, but not for thirty NASA executives who gathered at a meeting in Washington chaired by Paine. He went around the room and heard representatives of the centers responsible for manned flight say they were ready. At the end of the meeting, Mueller declared "there is no technical reason not to fly Apollo 8 as a lunar-orbit flight." At last, Mueller was publicly aboard, however non-enthusiastically. Low was not impressed. "By this time," he told Sherrod, "I didn't care what Mueller thought."[30]

Paine asked most of the second and third-rank officials to leave and called an executive session where he conferred with the most senior officials: center directors, program heads, and close staff. Discussed were not only the merits of the decision but also how to communicate the decision to the media and public. It was suggested that the decision should appear a matter of logic and not a reaction to Soviet competition.[31] Finally, Paine retired to his office accompanied only by Mueller and Homer Newell, the latter being the Associate Administrator and "Chief Scientist," one who had not been particularly involved in the Apollo 8 decision-making process up to this time. Newell said he was for the decision, seeing "substantial technical benefits." Mueller stated that the incremental risks were as great as any flight previously undertaken in the program, but he nevertheless was now in favor of going ahead. That afternoon, Phillips prepared a memo for decision, listing the pros and cons of a flight and ending with a recommendation in favor. Phillips did not mince words on the risk of the SPS engine. With no LEM lifeboat, the SPS must work. There was no redundancy once the astronauts were in lunar orbit. Phillips stated in his memo: "The life of the crew depends on the successful operation of the Service Propulsion System during the Trans-Earth Injection maneuver." The memo went to Mueller, who concurred in writing with the Phillips recommendation. He sent it to Paine.[32]

The final decision was Paine's. Paine had thought about Apollo 8 for a long time. While reviews took place below him, Paine had conferred with Webb. Reflecting on Webb's advice and his own reasoning at this time, Paine recalled:

> [Webb] didn't tell me what to do or not to do. He simply said: "Be sure to think through the consequences of your decision. What if something happened and the astronauts wound up circling the moon forever?" I agreed that this was a terrible thing even to contemplate. But my view was that we had crossed that threshold. When we made the decision to go to the moon, we knew we'd have to be taking some pretty fierce risks along the way. Also, I was not as concerned about risk as people are today.[33]

At 4:00 p.m. Paine called President Johnson, who was meeting with President-elect Nixon, informing them both that he had decided to go to the moon on Apollo 8.

DEFENDING THE DECISION

The following day, November 12, Paine and his senior associates went before the media to announce the decision, which they termed "the most advanced mission" for Apollo 8. They were immediately grilled on the risk issue. Was NASA going to chance a lunar-orbit mission to head off the Russians? No, was Paine's response. The Russians' intent "did not play any part at all in our decision on this flight," he said. Why go now, without the safety feature of the LEM? Wouldn't it be better, the reporter asked, to wait some months until it was available? Again, Paine and his associates said No, the mission was within the bounds of acceptable risk, when all factors were considered. What were the "odds" of success, another reporter wanted to know. Phillips replied for the NASA officials that he was "not going to calculate a set of probability numbers for you. I feel that we're ready for the lunar-orbit mission and that we have every reason to expect that we will be able to carry out the full mission and succeed with it. If I wasn't convinced of that, I wouldn't have recommended such a mission in the first place."[34]

In the days that followed, there were scattered criticisms of the decision from the scientific community and other quarters, but nothing substantial enough to alter NASA's course. Mueller, among others, defended the decision, stressing the thoroughness with which NASA had gone about its risk assessment. Further, the actual execution of the decision involved various "decision points," he stressed, where NASA could make changes in the interest of crew safety. Most observers in Congress and the

media went along with NASA. After all, the space agency and its executives would shoulder the responsibility and blame if anything went wrong.[35]

THE DECISION IS CARRIED OUT

Paine made it clear to NASA and its contractors that he wanted to know about "any problem" that came up that would "increase the potential risk of the mission." NASA could still turn back.[36] It was not likely to do so. The momentum was palpable. In early December, the Soviet Union did not use an optimal launch window, causing NASA officials to conclude that for whatever reason the USSR had decided against a manned launch to the moon. The US was in the lead. More than ever, NASA pushed ahead.

Borman and his crew, meanwhile, trained every day, long hours, simulating every conceivable exercise they might have to perform in an actual flight. Borman, acutely conscious that his own life and that of his colleagues depended on the flawless functioning of the SPS engine, pushed Low and others to make certain last minute improvements in the device. These were made, Low later wrote, at considerable expense.[37]

On December 21, Apollo 8 soared into the atmosphere. There was no pogo effect, and the first decision point was attained right on schedule. The crew and mission control went for TLI -- Trans-Lunar Injection. Firing their rockets to reach escape velocity, the astronauts left earth orbit and sped toward earth's nearest neighbor. On December 24, the next decision point arrived when Apollo 8 reached the moon. Again, crew and mission control communicated. All went well. The astronauts fired their engine and dropped into lunar orbit. "See you on the other side," said Lovell to Houston as the spaceship sailed out of contact with earth to the dark side of the moon. In Houston, Paine muttered to himself, "Jim, I hope so. I hope so."[38]

When the spaceship reappeared and communicated again, all in Mission Control felt a sense of relief. The orbits continued. It was Christmas Eve, and the crew read, one by one, excerpts from the

Book of Genesis. On earth, hundreds of millions of people listened, in rapt attention. Ironically, what the astronauts also told the people on earth was that it was earth that was alive and special, not the dead moon. They had seen the first "earthrise" and their message would help lead to the initial Earth Day, in 1970. Wishing the people on earth a merry Christmas, the Apollo 8 crew now disappeared behind the moon and continued their journey.

On Christmas Day, the crew arrived at the moment all associated with Apollo 8 had most dreaded -- Trans-Earth Injection -- when the astronauts would use their SPS engine to extricate themselves from lunar orbit and direct their ship back home. The SPS maneuver was accomplished without incident. "Please be informed," Lovell radioed Houston, "there is a Santa Claus."

Everybody at NASA breathed a sigh of relief, especially those who had recommended or made the decision. Among them, Kraft had been particularly worried, as he had spoken with Borman's wife, Susan, shortly before the flight. Susan had hidden her fears from her husband, but did not do so from Kraft. "If you think the [Apollo] fire was bad," she told him, "wait until these guys get stranded in orbit."[39]

They were not stranded, and on December 27 executed their reentry procedure perfectly. The crew landed at night, and were found without difficulty. The mission could not have been more successful.

AFTERMATH

Just about everyone, including critics of the space program, agreed that Apollo 8 was a "magical" flight. The year 1968 had been painful for America. The Tet Offensive in Viet Nam showed how poorly the war was going for the US side; President Johnson was forced to announce he would not run for reelection; Martin Luther King and Robert Kennedy were assassinated; the civil rights movement was frustrated; and Johnson's Great Society had fallen into shambles. There were protests in the streets and at the Democratic National Convention. Draft cards were burned and fires raged in the nation's capital.

Time Magazine planned to symbolize the year by featuring "the Dissenter" on its Man of the Year cover. Then came Apollo 8, and the three astronauts replaced the Dissenter. The year ended on a surge of hope and patriotic pride.

For NASA, Apollo 8 was everything its proponents had hoped it would be -- and more. It helped pave the way for succeeding flights, especially Apollo 11, in July 1969, when a man first stepped on the moon, and was then returned safely to earth. The goal proclaimed by President Kennedy in 1961 was thus fulfilled. In Apollo 8, NASA had taken a great risk, and had garnered rewards of success.

CONCLUSION

Apollo 8 represents a textbook example of a successful risk-management decision. What were the factors critical in Apollo 8's success.

The first was the clarity of the problem for which Apollo 8 was a solution. The problem was the unavailability of LEM for its appointed December 1968 launch of the original Apollo 8. This delay could have jeopardized the achievement of the lunar landing goal within the decade. In addition, there was the possible problem, which many in NASA took quite seriously, of a Soviet fly-by of the moon in December. Competition and the race to the moon mattered to NASA.

The second was the solution. It was clear and unequivocal. A lunar fly-by and back would not only keep Apollo on schedule, but perhaps accelerate the sequence of flights. Also, it would meet the challenge the Soviets were thought to be presenting. Hence, there was an ideal match between problem and solution. This match made the "reward" for risk-taking clear to most in NASA.

Thirdly, having an able advocate was critical. George Low was strategically located and well regarded within NASA. He also checked his ideas with other key officials and technical specialists, thus building a coalition of support for the solution. As he did so, the solution changed, becoming even bolder. Instead of a fly-by, there would be a lunar-orbit mission. The advocacy coalition included those whose judgment was seen as relevant to the risk assessment process, such as Kraft, von Braun, Borman,

Debus, Phillips, and others. A mid-level administrator, Low made sure there was consensus within the organization, and it was a united group, not one man going to top management with an audacious proposal.

Another factor was the interim decision of Webb. The process of decision was marked by two milestone decisions along the way. The first, that of Webb, was the decision to proceed with preparations. The decision put the presumption in favor of Apollo 8, but did not close options. Webb's strategy was to keep options open, allowing technical assessment to take place giving his troops a chance to prove that they could accomplish their plan. Also, he wanted time for himself to build political understanding and support for the decision, recognizing the political risk to NASA and its supporters. Such a strategy meant avoidance of a premature announcement of the Apollo 8 decision.

Additionally, there was the final decision of Paine. As with the interim decision, this choice was important as much for process as substance. Before it was made, there was ample time for further assessment of risks. Mueller played an important role in the period between the two decisions. He was the devil's advocate, the counter to Low and other proponents. His role as skeptic helped clarify issues, and probably made for an even stronger consensus in favor of Apollo 8 when the decision finally came. Also, if something had gone wrong during the flight, Paine could show the process of decision had been thorough. The assessment was based on collective engineering judgement rather than a calculation of probability numbers.

A sixth factor was the prompt implementation. Those charged with implementation were part of the decision-making process. Full preparation began immediately after the interim decision. Everyone understood the risks, including the astronauts. Borman even had the opportunity to design the flight plan, and see to it that the SPS system, regarded as the riskiest component of the spacecraft taking the crew to the moon and back, was technically improved.

The seventh factor was the clarity of responsibility. NASA took the risk and would have taken the blame. When Apollo 8 succeeded brilliantly, NASA received the reward it most wanted-- namely, the

chance to move rapidly forward to complete the Apollo mission and accomplish the Kennedy goal on time. Apollo 8 thus proved a pivotal point in America's race to the moon.

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REPAIRING THE HUBBLE TELESCOPE

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The Hubble Telescope repair is widely regarded as one of the most significant missions in NASA's history, probably the most dramatic since Apollo. The risks were stark and clear. The Hubble Telescope had been hailed as marking a revolution in astronomy. A telescope in space would not have to view distant objects through the obscuring effects of Earth's atmosphere. It would therefore be able to see virtually the end of the known universe, and hence back to the near-beginning of time as we understand it. Poised for a great leap forward, astronomers had worked for years with NASA engineers and contractors to bring Hubble to the point of reality. In 1990, the $1.6 billion machine, four stories high, was launched by the Space Shuttle.[1]

It was only a short time later, when the first photographs came down, that scientists and NASA were devastated to discover the primary mirror of the telescope had a flaw due to a manufacturing error made ten years earlier. The vision was impaired. While the pictures were still in advance of what could be achieved on the ground, they were still blurred and far from what had been expected. There was gloom everywhere among the thousands associated with the development and use of the new technology.

News of the Hubble fiasco could not have come at a much worse time for NASA. It had been only four years previously, in 1986, that Challenger had blown up, killing all astronauts aboard. Recovery had been slow and painful for the space agency. Just when NASA thought its credibility was

about to be redeemed, Hubble was shown to have major problems. Moreover, NASA was at this time engaged in a very contentious campaign to sell the program that would be its next major venture, the space station. Critics of the space station seized on the Hubble debacle to ask: how could NASA be trusted to construct a space station when it could not build a telescope?

Could Hubble be repaired? If Hubble could be fixed, especially in space, NASA could show its critics it still had "the right stuff" to follow through on grand designs. If it could repair Hubble in orbit, NASA could show detractors that it could conduct serious operations in space, including the building of a space station. A problem -- Hubble repair -- could be turned to opportunity. The risks, however, were immense, for repairing Hubble would entail potentially longer and more complex spacewalks and manipulation of tools by astronauts than ever before attempted. One mistake could make Hubble even less useful, or take the life of an astronaut in the vacuum of space. Unless NASA succeeded, its reputation would be scarred and space station jeopardized. The risks of action were offset by the political risks of inaction.

ANTICIPATING RISK

NASA designed Hubble to last 15 years in space. Wear and tear -- maintenance -- was expected and included in planning that went on for years prior to the actual launch.

The concept of a telescope in space went back to the 1960s, and began moving toward fruition in the 1970s. Initially, it was felt that the telescope would be retrieved from orbit by the Space Shuttle in five-year intervals. On Earth, the telescope would be refurbished and sent back via Shuttle. The on ground servicing would be supplemented by in-orbit work every two and a half years. Indeed, with a Shuttle that was seen as making virtually as many launches as necessary, routinely and cheaply, maintenance was not viewed as a major problem.

But Shuttle turned out to be far more costly, its launches less routine than originally believed. The notion that Hubble would have to be serviced in space took hold in the 1980s, and as it did, the design of Hubble began to increasingly incorporate an array of devices that would ease the repair task for astronauts. Fasteners, larger handles, foot restraints, receptacles, and other means were part of the Hubble framework -- all with the aim of facilitating repair in space.

When Hubble was launched in April 1990, NASA and its astronomer-users were already thinking ahead to what might be needed on the first maintenance mission, deemed routine, in 1993. Perhaps some "fine-tuning" of the apparatus might be necessary, but nothing special was anticipated given the time, energy, money, and apparent care that had gone into the making of the Hubble Telescope.

THE "SPHERICAL ABERRATION"

The joy and optimism that accompanied Hubble's launch soon gave way to chagrin and dismay when the blurred pictures came back to Earth. Senator Barbara Mikulski, chair of the subcommittee in charge of NASA's budget, called Hubble a "technoturkey." TV comedians joked about Hubble's need for glasses.[2] NASA could not understand what had gone wrong and appointed an investigating panel under Lew Allen, Director of the Jet Propulsion Laboratory (JPL). In June, the results of the Allen panel's work were in, and NASA announced sadly that the blurred vision was due to a "spherical aberration" in the primary 94.5" wide mirror. The manufacturer, Perkins-Elmer, had ground the mirror perfectly -- to the wrong specification. As a result, the Hubble Space Telescope's primary mirror -- the largest ever launched in space -- was too flat at the edge by an amount equal to 1/50 the width of a human hair -- just enough to make a big difference in quality of image. Incredibly, the error had gone undetected over 10 years between the time it occurred and launch. The manufacturer was at fault and so was NASA, for poor supervision.[3]

DESIGNING A TECHNOLOGICAL FIX

NASA appointed another committee, called the Hubble Space Telescope Strategy Panel, under astronomers Holland Ford and Robert Brown, to determine what, if anything, could be done to repair the flaw. Meanwhile, NASA and the astronomers labored to make the best of a bad situation -- the pictures Hubble was returning were still worthwhile.

In the fall and winter of 1990, the repair panel weighed various options. Bringing the telescope home for repairs was a possibility, but that carried risks of damage from landing and re-launch, along with costs of an additional Shuttle flight. Repair-in-space was far better if it could be done. As noted, a routine maintenance flight was already scheduled for 1993. This flight could now be used for what amounted to an emergency repair.

It was determined that the mis-shaped primary mirror, located inside Hubble, could not be replaced or repaired in space. In effect, Hubble would require "contact lenses." These lenses would need to be placed within Hubble so as to intercept the light going to the primary mirror and coming from it, so as to focus it correctly for various optical instruments inside.

Correcting the line of light through one contact lens, the Wide Field and Planetary Camera (WF/PC), was relatively doable. It had been intended prior to launch that this instrument, already in Hubble, be replaced with a more advanced device in the first servicing mission. Work on the replacement had been underway prior to the discovery of the vision problem. Experts could modify the optical surfaces of a set of coin-sized mirrors already in the substitute's optical design, thus re-routing the light. This new lens would help, but was insufficient for changing the direction of light to certain critical instruments. All around the world, specialists pondered what to do. One day, while in the shower, Jim Crocker, an engineer at the Johns Hopkins Space Telescope Science Institute, looked up at the shower head sending water in segmented streams. It dawned on him how to solve the problem. It would be possible to remove from Hubble a particular device and install in its place a box containing a mechanical

arm holding coin-sized corrective mirrors. These mirrors would go between the primary mirror and the instruments in question. The light would be refocused as necessary to these instruments. The repair panel called this second contact lens COSTAR, for Corrective Optics Space Telescope Axial Replacement.[4]

By January 1991, NASA knew from its repair panel that the combination of a replacement for the WF/PC and the COSTAR invention could restore most of the capability that had been lost. To make room for COSTAR, a telephone booth sized apparatus, the least used of the group of optical devices Hubble contained would be sacrificed. The cost of these repairs would run approximately $14 million for WF/PC, and $30 to $40 million for COSTAR. NASA now had a strategy for repair. It had already decided to replace WF/PC. It had to make a decision about COSTAR. However, the course of action was complicated by other problems appearing with Hubble.

There were at least two other major malfunctions being detected. First, the wing-like solar panels that helped power the telescope were not performing as they should. At least one of them was vibrating sufficiently to upset the precision the telescope needed to aim accurately. Second, some of the gyroscopes required to maintain Hubbell's position in space and capacity to correctly point in the direction of distant objects were failing. Hubble had redundancy in gyros -- it could survive with three of six working. Right now, there were four that were functioning well, not much margin for error.

The more repairs that had to be made, the more extra-vehicular activities (EVAs) or spacewalks would be required by astronauts. The more fixes astronauts attempted, the greater the chance they could make the problems of Hubble worse by contaminating the instruments. The more spacewalks attempted, the more likely astronauts could be in danger. The risks of decision were adding up, as were those of delaying the decision too long.[5]

During 1991, NASA mulled over various issues involved. The immediate shock of Hubble's flawed vision had worn off, and NASA and the astronomical community were finding ingenious ways to

maximize the science-value of the images Hubble was providing. It is noteworthy that NASA and its scientific constituency were working together to solve the problems they saw as best they could, rather than pointing the finger of blame at one another.

NASA had yet to make a final decision about Hubble repair, but it made an essential interim decision in October 1991, giving Ball Aerospace Corporation a contract of over $30 million to develop, in association with others, COSTAR.[6] The European Space Agency (ESA) was responsible for the solar arrays, and would have to make the necessary investment to replace these should the final decision be made to include them in an overall mission.

THE GOLDIN TRANSITION

In early 1992, Richard Truly was fired by President George Bush as NASA Administrator. The reason was a well-publicized feud between Truly and Vice President Dan Quayle, head of the National Aeronautics and Space Council. Truly was replaced by Dan Goldin, an executive with TRW, who had spent most of his career in classified technology programs. Goldin had worked for NASA early in his career and obviously was a space enthusiast. He appeared on the scene in March and was confirmed April 1. Immediately, he made it known that he believed NASA was out of step with fiscal reality and too conservative technically. He made "better, faster, cheaper" his mantra, and started shaking up the agency. While Goldin's primary orientation was to bring down costs of space programs generally, while making the Space Station more politically acceptable, he inherited the Hubble Problem, and understood this program as symbolizing NASA's capability.

One of Goldin's first moves was to select Major General W. "Jeb" Pearson III to replace astronaut William Lenoir as Associate Administrator for the Office of Space Flight. A proven manager, Pearson had been Deputy Commander of marine forces in Operation Desert Storm. Hubble was a program nominally under the Office of Space Science and Application (OSSA), but its connection with

manned flight was close due to its means of launch and in-space repair, the Shuttle. Given the extent and complexity of the repair that was shaping up, the role of Pearson and his Office of Space Flight inevitably grew as Hubble repair planning evolved.[7]

The momentum behind Hubble repair increased in April when Story Musgrave was chosen to lead the team of astronauts who would perform the EVAs and do the work of repair. At 56, Musgrave was senior among astronauts not only in age, but also in experience. He had joined the astronaut corps in 1976 and gained considerable knowledge with the Space Shuttle and EVA. A man of much learning and many skills (he was a medical doctor as well as a student of mathematics and literature), Musgrave was the kind of man believed up to the demanding task ahead.

Similarly, another NASA veteran, J. Milton Heflin, was chosen to be flight director and help manage the mission from his post in Houston. With ten years at Mission Control and twenty Shuttle flights in his background, he had, in his role, the kind of testing Musgrave had as an astronaut. They began to prepare for the mission, even though it was still not a 100 percent certainty it would take place.[8]

In mid-May, Goldin went to Houston to observe a repair mission first-hand. The Space Shuttle Endeavor was launched, its objective to capture and fix an Intelsat I communications satellite which had experienced a malfunction. The plan was for two members of the crew to approach the spinning satellite, insert a specially-made tool in the central motor chamber about which it turned, and fire a grappling device that would seize the chamber and gradually halt the satellite spin. They would then make the needed repairs and put the satellite back into service

Unfortunately, the $7 million tool, which worked on ground, failed to connect in space, and efforts to insert it merely pushed the satellite away from the astronauts. Mission Control in Houston and the crew improvised. A third astronaut went outside the crew compartment of the Shuttle. The three astronauts stationed themselves in the payload bay of the Shuttle, while a fourth astronaut eased the

Shuttle toward the spinning satellite. They grabbed the satellite, slowed its rotation, and pulled it into the cargo bay, where they made the repair.

Publicly, Goldin praised the astronauts and Houston for their courage and creativity. Privately, he and others in NASA were critical. They had taken serious risks, risks that were possibly unwarranted in the case. Moreover, the fact that their training on Earth proved a poor match with what the astronauts encountered in space implied that the far more demanding Hubble Repair mission needed more thought. Goldin appointed a special NASA task force to study the overall question of repair work in space.[9]

The Intelsat experience made NASA more circumspect about Hubble Repair, but did not delay the preparations. In August, three more astronauts joined the Hubble crew: Tom Akers, Kathy Thornton, and Jeff Hoffman. As with Musgrave, adjectives like "experienced" and "seasoned" applied. It was also decided that training on the ground and in the water-tank at Marshal Space Flight Center in Huntsville, Alabama would be complemented by greater learning from practice in space. In the next series of Space Shuttle flights, already scheduled, "EVAs of Opportunity" were planned.

NASA officials wanted the Hubble crew to perform the minimum number of spacewalks necessary to complete the job -- but the list of needed repairs was growing lengthier as more went wrong with Hubble. In September, a power supply problem eliminated half the capabilities of an instrument called the Hubble Faint Object Camera, and a third gyro failed, meaning Hubble was down to the minimum three needed for it to perform even its limited function. Pearson appointed a review team under former Apollo astronaut Tom Stafford to give him advice on repair issues.

In December, the remaining members of the crew were chosen. Richard Covey would serve as Commander of the Shuttle; Ken Bowersox would work with Covey as pilot. Claude Nicollier of the European Space Agency would man the Shuttle's 50-foot robot arm. Added to the earlier selections, the Hubble repair team had 16 Shuttle flights among them.[10]

The importance of the flight caused Pearson, at the suggestion of Stafford, to centralize management for this particular mission. For most "routine" Shuttle flights, the locus of control for preparation, training, and planning was at Johnson Space Center in Houston. Headquarters supervised, to be sure, but did not manage in a day-to-day sense. Not with Hubble Repair. Pearson appointed Randy Brinkley, a marine aviator who had served with Pearson during Desert Storm, and who now was his assistant in Washington, to a new position: Mission Director. He was sent to Houston to manage Hubble Repair. The Brinkley role -- representing Headquarters at Houston -- harkened back to a similar model used in the Apollo era, when JSC had far less autonomy than it did now. But Hubble Repair was high profile and this mission could not be handled in a routine or decentralized way. It had to get special priority throughout the NASA organization. Brinkley could get to Pearson without going through layers of bureaucracy. And Pearson could get to Goldin. Close connections helped greatly in getting decisions made and priority in resource allocations.

Goldin did not necessarily wait to be invited to participate in Hubble Repair decision-making. There were existing NASA review committees, but Goldin was extremely anxious not to have his options foreclosed by his own organization. In January 1993, he asked Joe Shea of MIT, head of the NASA Advisory Committee and a NASA official during Apollo, to head yet another panel to determine the feasibility of Hubble repair. He wanted a group of outside experts to take one last look before he gave the final go-ahead for a space-based repair mission.[11]

MOVING FORWARD

The Shea Committee read reports from other review groups and questioned NASA officials. Meanwhile, under Brinkley, NASA tightened its management controls over contractors involved with Hubble repair. Robert Lilly, a NASA engineer, told Science magazine in February that the agency had to make organizational fixes if it were to accomplish technical fixes on Hubble. He said we have to

overcome "the kind of incestuous cycle that got us in trouble before with contractors." NASA had given contractors like Perkins-Elmer too much leeway. Now, there would be no lack of oversight. NASA also would do its own testing to double-check the contractors' testing.[12]

NASA engineers checked equipment while astronauts trained. At the same time, the EVAs of Opportunity commenced. A Shuttle went up in January. During the flight, astronauts went to the cargo bay. They carried one another around to determine problems of lifting and moving large masses in the absence of gravity, as would be required in Hubble repair. A second EVA of Opportunity occurred in an April Shuttle mission. An astronaut anchored to the end of the Shuttle robot arm grasped and moved a second astronaut about in the cargo bay to simulate moving the WF/PC into position for installation. He practiced guiding his crewmate onto a work platform to simulate guiding the camera into the telescope.

In May, the Shea panel reported. The bottom line was that servicing Hubble in space was "feasible." The risks and costs of bringing Hubble back to Earth, repairing it, then launching again were prohibitive. Moreover, Hubble was designed to be repaired in orbit. However, the repair mission was unprecedented in its duration, complexity, and difficulty. Hubble repair required focused management attention, and the Brinkley appointment was "encouraging," but "further senior management attention" was required. While feasible, the repair mission had expanded to include many more repairs than the initial viewing problem. Priorities had to be clarified, and the Shea panel suggested it would be prudent for NASA to plan for a second service mission.[13]

The Shea report all but clinched the basic decision to repair Hubble, if not all the particulars. Had the panel said the mission was not feasible, Goldin might well have acted to halt preparations. Since the Shea report had given approval, it reinforced existing momentum, and a launch target in December became more solidified. Goldin did not make a grand announcement. He simply let the preparations underway continue. The intensity of training increased.

For Musgrave, greater intensity meant actual physical pain. In June, Musgrave's fingers became frost-bitten during a particularly long simulation in a chamber whose temperature was brought down to the extremes of space. Astronauts had worked in space before, but not as long as they would in Hubble repair. Not only was space cold -- up to minus 300 degrees F. -- but so were the tools Musgrave used. The reason for long practices in extreme cold was that work on Hubble could not expose the delicate equipment to the light of the Sun. In an effort to protect Hubble equipment, NASA had designed a trajectory to minimize sunlight. NASA might have forgotten the increased risks to astronauts. A compromise had to be found. Mission designers went to work and found an attitude for the Shuttle that would minimize sunlight while maximizing the retention of solar heat. Gloves were redesigned so they would be even warmer while still flexible. Tools would be stored in the orbiter cabin, rather than cargo bay, to keep them warm as long as possible.[14]

Practice continued on the ground, in water tanks, and in space. During a June Shuttle flight, one astronaut moved a companion around the cargo bay, again to test various ways to manipulate large masses in weightless conditions. In September, two astronauts twisted bolts and utilized a swivel work platform during a Shuttle flight.[15]

POLITICAL STAKES RISE

NASA was doing everything it could to make the mission succeed, including spending extra money. The replacement cameras -- WF/PC and COSTAR -- would together cost $64 million, more than expected. Another $2 million was spent to make the astronaut training more realistic, augmenting the water tank at Marshall with a better mock-up of the robot arm. ESA spent funds for replacement solar arrays. The flight of the Shuttle would cost one-half billion. The total was estimated as approximately $630 million, but a lot depended on how the calculation was done. In view of NASA's political stakes, the technical costs were not the major issue.

In August, NASA had suffered another blow. The Mars Observer Space Probe, costing $1 billion, went dead just as it neared the red planet. No one could understand or explain what went wrong. NASA again was besieged with criticism from Congress and ridicule from TV jokesters. The Mars Observer disaster came as NASA's Space Station was under critical scrutiny from the White House and sharp attack in Congress.

The new President, Bill Clinton, had priorities other than space, even though his Vice President, Al Gore, was known as a space buff. Under pressure to find budget savings, Clinton looked at NASA as a politically safe place to cut. He eventually backed the Space Station, but required it be scaled back and that Russia be enlisted as a partner. In Congress, the Station survived an arduous debate, but NASA's legislative friends told the agency the future was extremely grim if Hubble repair failed.[16]

NASA understood the political realities of 1993. It was desperate that Hubble succeed. What was success? In September, Aviation Week and Space Technology echoed the Shea panel advice admonishing NASA not to try to do too much on one mission. It noted that over time the repair list had grown substantially, and some repairs had lower priority than others. So much of what was judged success in space depended on perception, the trade journal said. If NASA corrected the problems over two missions, it would lower the threshold of success. Right now, the magazine wrote, it would take five days of EVAs to get all NASA wanted done in one flight.[17]

NASA felt that if it could accomplish all its goals in one flight, it should do so. Edward Weiler, Hubble chief scientist at NASA, said, "We've got to get it right this time. We're not going to launch until all the t's are crossed and the i's dotted."[18]

NASA worried about having to postpone the flight (or flights) when tests showed one of the replacement cameras -- the all-important WF/PC -- was not performing as it should. Scientists, engineers, and optical experts from all over the country were mobilized to diagnose the problem. By the end of October, it was concluded that the camera was fine, the tests were wrong.[19]

Reviews continued and all favored a "go" decision. In November, it was calculated that there had been 195 formal recommendations by 12 different review teams. Also, it was determined that by December the crew would have spent 700 hours in EVA training, 400 of them under water. These numbers were twice those of any other crew in history. Brinkley was preparing for worst case situations, and he had upper management practice coping with various high risk scenarios, including "situations that pitted the safety of the orbiter versus the survival of the Hubble." Priorities were clarified, the order of work to be done, and ways to deal with various emergencies, including the need to abandon work and head for home.

You have to rehearse and rehearse again, said Musgrave. As the flight date approached, he could envision every detail of the mission and his role in it, every foot position, every hand hold, how far forward to lean, how far backward, how much pressure to exert on an object, how little, every twist and turn of every tool. And he expected surprises and prepared himself mentally for these. All aspects had to be in his mind, he recalled. He said he felt the way a ballet dancer must feel before a critical performance, except that his dance was in space, and NASA's whole future seemed to be riding on how he and the other astronauts did. The most experienced astronaut, Musgrave had a routine for getting ready for a flight, one that ended in an unusual way. "The night before a launch," he said, "I go and lie in the ocean and let the waves roll over me. I look up and watch the satellites go by and I know that tomorrow I'm going to be one of these."[20]

If Musgrave sensed the sublime, others in the crew saw danger. Covey, the Commander, had been in Mission Control the day Challenger had gone up, and was the last man to communicate with the Shuttle. "Challenger, go at throttle up!" he told the doomed spaceship. The violent explosion that followed was etched in his memory forever. "Getting to orbit," not the spacewalks, worried him most.[21]

The mission was ready. NASA was going for broke, scheduling five spacewalks in an 11-day total mission. "We're perhaps taking on more than we can accomplish," worried Kyle Herring of the

Johnson Space Center. Weiler declared: "This project is going to be in the history books, whether as a national disgrace or as a triumph."[22]

THE REPAIR FLIGHT

On Thursday, December 2, Space Shuttle Endeavor rocketed upward. Once safely in orbit, Covey and Bowersox maneuvered Endeavor into a path to rendezvous with Hubble. On December 4, rendezvous was accomplished, and Nicollier used the Shuttle's robot arm to grasp the telescope and pull it to a service platform in the cargo bay. "Houston, its really big!" exclaimed Bowersox when he first saw the 43-foot long, 12-ton machine.[23]

All repair missions were scheduled at night, a decision based on various technical factors, including the path Endeavor had to take to intercept the telescope. There would be five spacewalks on successive nights. Musgrave and Hoffman, known as "the odd couple," had the odd-numbered spacewalks (1, 3, and 5). Kathy Thornton and Tom Akers had 2 and 4.[24]

On the fourth day of flight, Musgrave and Hoffman stepped out of the protection of their cabin and into the Shuttle's cargo bay and began working. Hour after hour, they manipulated equipment while in bulky spacesuits. They had honed their bodies through exercise to reach an athlete's edge of endurance, and they needed all the energy they could muster. The primary task of the pair was to replace non-functioning gyroscopes with ones that worked.

They also had to replace certain electronic control units and fuse plugs. It took a near-record seven hours and fifty-four minutes of non-stop work, during which problems developed and Musgrave successfully improvised a solution. Exhausted, Musgrave was also exultant. "I love it, I just love it," he exclaimed.[25]

On day five of the flight, while Musgrave and Hoffman rested, Thornton and Akers took their turn. Their task was to remove shaky solar panels and replace them with new ones. These were 40 foot,

400 pound objects. One of the arrays, still functional, would be stored in the Shuttle's cargo bay. The other would be jettisoned as space debris. Thornton, anchored to the Shuttle robot arm, held the damaged array while Akers, attached to the ship by a tether, moved freely to disconnect the electrical fasteners to Hubble. Nicollier then moved Thornton high above Endeavor where she released the gleaming, golden array. "Holey moley, piece of cake...it looks like a bird," she yelled as the array moved away. After Thornton and Akers were finished, Joe Rothenberg, a principal Hubble scientist-manager, remarked: "Its a great morning. We've been up to bat twice and our crew has hit two home runs."[26]

On day six, Musgrave and Hoffman donned their spacesuits for an all-important assignment: replacing the WF/PC with a new camera that would correct some of the optical problems caused by the spherical aberration on the primary mirror. Hoffman attached himself to the robot arm while Musgrave floated freely. They loosened the bolts that latched the existing WF/PC to the telescope, then slid the piano-sized apparatus out. After moving it out of the way and securing it, they slid the new camera into exact position on guide-rails and slid it into its cavity within the telescope. It was "not difficult," said Hoffman, but it was "very, very critical" not to make any mistake. He compared the work to walking on a narrow mountain ledge with a 2000 foot drop on either side.[27]

The next day, number seven in the mission, Thornton and Akers performed the other optical operation Hubble required. They removed the device that had been chosen for sacrifice, the High Speed Photometer, to make room for COSTAR. Clamped to the robot arm, which Nicollier manipulated, Thornton carefully pulled out the photometer and moved it out of the way so that it would not interfere with further work. Then, together, she and Akers gently slid the 700-pound, phonebooth-sized COSTAR onto guide-rails. Then, they pushed it into the Hubble cavity, like a dresser drawer. Finally, they made the necessary electrical connections. Not only did they perform this utterly essential task perfectly, they did so in far less time than expected.[28]

On the eighth mission day, and fifth spacewalk, it was again time for "the odd couple." The most critical priorities behind, Musgrave and Hoffman attended to a number of miscellaneous tasks. These included installing a solar array electronics unit, a high resolution spectrograph, and contamination control covers on magnetometers. When they finished, they had done everything expected, and "some things extra." NASA officials were utterly exultant.[29]

Over the remaining days of the mission, nine through eleven, the astronauts redeployed Hubble to a proper orbit, and then came home, their journey having encompassed 4.4 million miles. They landed safely just after midnight, at 12:25 a.m., December 13.

REACTION

After the crew redeployed Hubble, President Clinton and Vice President Gore telephoned the astronauts from the White House. Clinton told them the flight was "one of the most spectacular space missions in our history. You made it look easy." Both the President and Vice President promised to support a more vigorous space program and said they hoped the success would restore congressional and public backing.[30]

Back on Earth, NASA savored the plaudits. "Virtuosos in Space" -- that was how the New York Times characterized the mission. It was a "near-flawless performance," the Times, usually critical of NASA, declared. "This was billed as a do-or-die mission, and in one sense it was. The manned space program would almost certainly been put on hold had an accident disabled the Shuttle, the Space Telescope, or both. Instead, the clear demonstration that the astronauts can perform work in orbit (five demanding space walks in five days) increases hope that they will be able to carry out the far more complex and arduous job of assembling a Space Station." The Washington Post called the mission "mesmerizing. Even some of NASA's land-bound critics are applauding the success of the agency's riskiest and most complex mission."[31]

Senator Mikulski, who had at the time the flawed mirror was discovered called Hubble a "technoturkey," now sang a different tune. This will "go a long way to restoring congressional confidence in NASA's ability to carry out its complex duties." Congressman George Brown (D., Calif.), Chair of the House Committee on Science, Space, and Technology, declared: "The restoration of confidence in NASA's ability to plan and manage such tasks will make my job of lobbying for a stable space budget much easier."[32]

The New York Times and others qualified their cheers somewhat by pointing out that it would still take a while to determine just how successful the repair mission was. In astronomical terms, the answer came in January 1994. At a press conference attended by NASA officials, Senator Mikulski, the Vice-President, Science Advisor Jack Gibbons, and other scientific and political notables, photographs were held up that presented views from Hubble taken before and after the repair mission. The contrast in visual acuity was dramatic. "It's fixed beyond our wildest expectation," Weiler exclaimed. Hubble would detect objects as far as 10 to 12 billion light years away. Jim Crocker, the man who had devised COSTAR, said, "it could detect fireflies in Tokyo." Everyone spoke in superlatives. The results exceeded NASA's "wildest dreams," said Goldin. The success "signals an immediate improvement in the space agency's prospects," announced a beaming Mikulski, who continued: "The trouble with Hubble is over. We now know that NASA has the right stuff."[33]

CONCLUSION

Hubble was a great success in technical and political terms. Aviation Week and Space Technology, which had recommended that NASA accomplish the feat in two missions rather than one mission was congratulatory, but it warned NASA that the euphoria would not last. In the short-run, there might be a positive "bounce" that would help the space budget. In the current budget climate, how lasting would be this bounce? In view of the politics as the magazine saw them, the risks of failure were

greater than the long-term gains of this admittedly grand success. "Failure would have been disastrous."[34]

The magazine was correct about NASA's taking a huge risk, but it was wrong in minimizing the importance of the "bounce." The short-term in politics often determines the long-term. NASA had to do more in the difficult budget climate of this period, when Big Science projects like the superconducting super collider were being killed, and the Space Station was the next prime target for budget-cutters. NASA had to succeed impressively, and by taking the extra risk of packing all the repair-work into a single mission, it succeeded spectacularly and got a "bounce" that may well have saved Space Station at a pivotal moment to face another day. Ironically, as Hubble enthusiasts later noted, Hubble repair may have saved Space Station, but the victory it portended for manned space might mean less dollars for Hubble science down the line, as the overall space budget was squeezed.

What were the factors critical to success in NASA's risk management decisions? Some of the leading participants had their own answers.

Musgrave said "the reason Hubble [repair] worked was, number one, Hubble was incredibly friendly to being serviced by an EVA crewperson, and we were able to attack all the details in all the environments and build a mission." Also, he declared, "NASA had the courage to go for it all." Finally, "We went into this scared. It meant an incredible amount to us and to others to get this job done."

Hoffman's view was that the "reason for the success of the mission...is NASA went for it 100 percent. Everybody was behind this mission."

"It shows that we can do what we say we can do," said Jeremiah Pearson. "We've learned that if you plan, train, replan, retrain, you come out with success."[35]

In summary, the stakes were as high as they could be; everyone in NASA understood that fact. Sufficient resources were made available to accomplish this mission; a special management system was created, one overseen by senior management; and scientists, engineers, administrators, and astronauts all

pulled in the same direction over a span of three years. By preparing for the risks so completely, they mitigated these risks. Politicians contributed also, by putting heat on the agency to succeed, while not micro-managing the actual decision-making process. NASA was able to focus on a single goal: Hubble repair. In this instance, individuals, organizations, and technology coalesced.

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[1] The author is indebted to Joseph N. Tatarewicz, whose unpublished manuscript, "The Hubble Space Telescope Servicing Mission," proved a source of information and insights.
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[3] Ibid. Kathy Sawyer, "Defect Ruins Focus of Space Telescope," The Washington Post, June 28, 1990.
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[33] John Noble Wilford, "Hubble Repair Called a Success and NASA Says Pictures Show It," The New York Times, January 14, 1994.

[34] James Asker, "So Far, Hubble Checks Out Well," Aviation Week and Space Technology, January 3, 1994, p. 47.

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PRIVATIZING THE SPACE SHUTTLE: RISK MANAGEMENT AT NASA

by W. Henry Lambright

Privatizing the space shuttle has been a decision-in-the making since at least 1975--seven years before the formal test-flight program formally ended. It has continued to be a decision-in-the-making throughout the 1980's and 1990's, albeit considerably slowed by the Challenger disaster of 1986. There has never been a "big" single decision, in the manner of President John Kennedy's decision to go to the moon. Instead there have been a myriad of small decisions, punctuated by two truly significant choices: one in 1983 to delegate shuttle processing between flights to industry; another in 1996 to add certain launch operations, astronaut training, and mission control activities to work turned over to industry. These decisions are leading inexorably toward moving "the world's most sophisticated flying machine" from control by government to control by private contractors.

To be sure, the development and application of this unique spaceplane has always involved contractors. A legion of NASA civil servants has managed the contractors closely and maintained close oversight of the contractors' technical work. In a privatization model, "oversight" would be replaced with "insight," as government moved back from day-to-day decisions to let industry "run" the shuttle program, rather than helping government do so. NASA would be to industry as FAA is to the airline companies.

As Challenger revealed all too sadly, however, the sheer complexity of the shuttle, and danger of space, makes this technology different from an aircraft. Many critics of privatization scoff at the aircraft analogy and warn that a profit-making mentality would raise risks as industry cut corners to make money. A major report to NASA in 1990 by a blue-ribbon group of space experts said the shuttle would always be "experimental."[1]

In theory, a technology moves along a continuum from R&D to operations , from the new and untried to the mature and routine. As it does, management systems surrounding the technology change, and government presumably can give way to private sector management. But the shuttle seems interminably in an in-between state, no longer R&D, but not routine either. Everyone dreads another Challenger, even though statistical odds say one is inevitable. A national symbol, the space shuttle has been the single most important technology defining the space program since the Apollo era. Even as the nation and world look ahead to what has been called the "Space Station Era" of the early 21st century, and NASA begins to develop a new versatile rocket-plane to replace the shuttle, the space shuttle will remain the workhorse of the space program, without which a space station cannot be built. It is very likely the shuttle will fly at least until 2010.

From the program's inception in 1972 through 1996, NASA has spent $64.7 billion--the equivalent of $94.4 billion in today's dollars-- on the space shuttle. And that does not include the agency's work on shuttle payloads. Including all shuttle development costs and adjusting for inflation, the cost of a single shuttle flight costs $1 billion.[2]

The space shuttle has never met its early goals to be "cost-effective" and serve as the one federally operated space transportation system that could meet all needs. However, it has been an exceptional space system that has made possible a long list of accomplishments in manned space, space science, and earth observation. Most importantly, it has helped maintain the United States capability to put human beings into space. Without the shuttle, the glory of Apollo might well have been followed by the end of manned spaceflight in America.

It is not the purpose of this paper to debate the merits and limits of the space shuttle. Nor is it the aim to reconstruct the tumultuous history of this critical and, at the same time, ill-starred program. Rather, the purpose is to trace the decision-making process with respect to the privatization issue. Even more focused, the paper highlights the question of risk management in privatization. Whatever else it is, the space shuttle has always been a high-risk technology. The management of risk -- who manages? how? -- has always been part

of the privatization debate -- never more so than today. In the midst of a drive to cut the NASA budget, downsize big government, and advance to the new frontier in space R&D, privatizing the shuttle is tempting to decision makers.

In 1996, with a record of flights over a decade and a half that showed a launch success rate of 99%, the shuttle was called by many prominent observers at last ready for transfer to the private sector. The two largest NASA shuttle contractors -- Lockheed Martin and Rockwell -- formed a new joint venture, called United States Alliance (USA). On October 1, NASA signed a $7 billion contract with USA that the trade magazine Aviation Week & Space Technology called "the first step in the agency's plan to partially privatize its fleet of orbiters." [3] Under what was called the Space Flight Operating Contract, NASA placed 85% of shuttle operations work and responsibility in USA. While critics as important as NASA's Aerospace Safety Advisory Panel urged caution, NASA has also reorganized its shuttle management, decentralizing power from headquarters to centers. Those NASA officials who have disagreed with the trends have resigned in protest. Defenders of the policy say the moves will not compromise safety and will save money at a time when NASA has no option except to cut back. Indeed, they say, the shuttle will be more secure because responsibility will be more clear-cut.

Prominent supporters of the privatization strategy say that NASA and the United States have reached a milestone in the history of the space shuttle. A review of decisions that led to this most recent step toward privatization will reveal many a twist and turn along the way, with risk a major factor in pace and direction. The decision to privatize the shuttle has been, and continues to be, a complex process, involving many actors and many choices. It can only best be understood by reflection on the history of the program.

LAUNCHING THE SPACE SHUTTLE

In 1969, after the successful completion of the Apollo moon-landing, the Administrator of NASA, Tom Paine, lobbied President Richard Nixon and others in his administration, especially Vice-President Spiro Agnew,

for another decision on the order of Apollo. A trip to Mars, or a giant orbiting space station, were favored. But in the political environment of the time, the President saw no public support for such a decision.

Paine reluctantly fell back from Mars and a space station to a program that was virtually an afterthought, a program to build a space shuttle that would move men and materials back and forth from earth to orbit. The space shuttle was essential to build a space station in any event. In January 1970, recognizing political and budget reality, George Low, NASA's deputy administrator, said -- " I think there is really one objective for the Space Shuttle Program, and that is to provide a low-cost, economical space transportation system. To meet this objective, one has to concentrate both on low development costs and on operational costs." [4]

To get a space shuttle, NASA had needed presidential approval, and that required effort. Paine realized NASA needed others to win Nixon's favor, and called the space shuttle a "national" technology to emphasize it went beyond NASA to the Pentagon and industry. The Air Force agreed to support NASA if NASA would design the vehicle to accommodate Air Force requirements.

The shuttle went through various designs in 1969 and 1970, with NASA favoring a two-stage, fully reusable system, with both stages manned and capable of landing on a runway like a conventional airplane. The estimated cost was $10-15 billion, a figure Nixon's Office of Management and Budget (OMB) found too high. Told to expect level budgets at $3.2 billion annually, Paine fought OMB, but Low felt NASA had little choice but to assume constraint.

Paine left the agency in September 1970, and Low served as Acting Administrator until February 1971, when James Fletcher took the helm. Fletcher saw NASA's survival at stake. Unless the agency got a presidential decision on the shuttle, it would wither away. To get the President to go along in the budget climate of 1971, the shuttle would have to be "cost-effective." Fletcher did not like the conditions, as he regarded the shuttle a great national resource. But Nixon was letting OMB take the lead on space. NASA contracted with Mathematica, Inc., among others, to find out what it would take to make the shuttle economical. In March 1971, Mathematica reported preliminary results that found the two-stage fully reusable

design was not economically justified, but that a one-and-a-half stage partially reusable vehicle was "cost-effective." Further reports, which assumed a large number of flights to lift payloads into space, reinforced the cost-effective finding. In August 1971, Casper Weinberger, Deputy Director of OMB, cautioned his colleagues, who were anxious to cut NASA still further, that enough was enough. He wrote Nixon that such cuts "would be confirming in some respects the belief that our best years are behind us." He stressed the symbolic nature of space as demonstrating US "super power status, and our desire to maintain world superiority." President Nixon wrote on Weinberger's memo, "I agree with CAP." The decision process shifted from whether there would be a shuttle to what kind of design it would have.

Nixon believed the space shuttle could have military value. He was also thinking, in late 1971 and early 1972, of the "battleground states" for his reelection. He regarded California as especially critical. The shuttle would mean more aerospace jobs in California, and they could make a difference. At the end of 1971, Fletcher and Low were informed by the White House and OMB that Nixon would go ahead with the program. In early January 1972, they flew to San Clemente, met with the President, and announced the decision. The shuttle the President decided to build was the partially reusable machine, which would meet DOD as well as NASA's specifications, and which was to cost $5.5 billion in development funds.[5]

NASA would thus survive, but NASA had gone along with the goal that the shuttle would provide cost-effective access to space. What was cost-effective would have to be reliable and provide routine access to space. What was routine would also, presumably, be risk-free.

PRIVATIZATION IS RAISED

It was not long after the Nixon decision to develop a space shuttle was made that privatization was raised as an objective. On December 30, 1975, in a memo to John Yardley, the Associate Administrator for Space Flight and the director of the shuttle effort, George Low noted that "one of the agency's main goals in development of the space shuttle has been to make access to space routine." While "realization of this goal is

still several years in the future, it is not too early to consider some of the longer-term implications of this," he wrote. "Specifically, once the techniques of operating the shuttle have been developed and validated, is there a possibility that STS [Space Transportation System] operations could be turned over to a mission contractor?"

As Low saw it, privatization had advantages: "First, early acknowledgment and preparation for eventual contractor operations of the shuttle will force us to develop shuttle operations to be as routine as possible. Secondly, it would eventually free our civil service manpower for what remains our prime agency mission, namely, advancing the frontiers of technology. Finally, having the shuttle operated under contract is a positive way of implementing one of the main thrusts of our institutional assessment, namely, putting more work in the hands of industry."

Low directed Yardley to undertake "an evaluation of the possibilities for eventual contractor operation of the shuttle." He told Yardley to study the pros and cons of the move, how it would be accomplished. While Low did not raise the risk issue, he did ask whether NASA could realistically take the full responsibility for Shuttle operations if it were a true contractor operation?"[6]

STUDIES

In 1976, NASA launched a series of studies. The first, by Aerospace Corp., concluded that the space agency should continue to operate the shuttle. In 1977, NASA asked the National Academy of Public Administration to look at alternate shuttle management methods, and NAPA also recommended NASA stay involved as the overall shuttle manager. Then came a study contracted from NASA to Booz-Allen Applied Research. At NASA's request, Booz-Allen brought in three aerospace contractors to help examine the concepts being discussed. The companies were Rockwell International, McDonnell Douglas and General Electric. Booz-Allen and the contractors all came to the same conclusion: "let the contractor do the majority of tne job and furnish his own services to the extent whether (NASA) can hold his feet to the fire for both safety and performance."[7]

THE FROSCH ERA

James Fletcher resigned as NASA Administrator in May 1977, giving way to President Jimmy Carter's appointee, Robert Frosch. Fletcher's legacy was the shuttle decision and thus the survival of manned space at NASA. His legacy also was a program that was underfunded and falling behind development schedule. None of the shuttle managers believed the shuttle could fly for at least two more years. Frosch determined the $5.5 billion development figure NASA had negotiated at the time of President Nixon's decision was low by at least $1 billion. His task became getting President Carter to agree to a funding increase.[8]

NASA had been planning for a fleet of five shuttles, but Carter in 1978 decided NASA would only have four. In 1979, however, Carter met with Frosch and agreed to fund the "overruns" and complete the development program. The prime reason for the President's favorable decision was that the Air Force needed the shuttle. As the shuttle had become, de facto, the principal means for future access to space, expendable launch vehicles were not being built. The Air Force as well as the CIA were users of the shuttle. Carter said that the due bill on the shuttle had been building over three administrations and would be paid.[9]

With the additional funds, Frosch could put the shuttle program back on track and plan for the first shuttle flight, seen as taking place late in Carter's term. With various technical problems, it turned out that the initial flight of the shuttle would take place not under Carter, but under President Ronald Reagan.[10] While Frosch dealt with the Air Force, and Carter with larger policy concerns, Frosch and his senior associates also looked ahead to the move of the shuttle from R&D to operations.

In 1978, testifying before Congress, Yardley said that the studies NASA had funded had shown no "practical way" NASA could turn over operations to industry, at least in the first decade of the shuttle program. Nevertheless, while maintaining NASA control, the agency did intend to shift more responsibilities to prime contractors instead of augmenting civil service and support contractors.[11]

Frosch in 1978 also spoke of a gradual transition. He had talked with Boeing and other companies who expressed interest in operations, but not in a particularly serious way. He thought privatization would be

12 years off, but that certain ground support tasks could come sooner. "The movement of the aerospace industry into the operation of the reusable shuttle will begin with their personnel running the pre-launch preparations and launch of the spacecraft," Frosch stated.[12]

Testifying before Congress in 1979, Frosch was asked about the privatization transition and responded that "we don't yet see how to go there from here right now." Nevertheless, he pointed out that the shuttle was different from Apollo, and would eventually be a "routine flight operation." Here, "it seems to us much more appropriate to build that into a consolidated industrial operation." He indicated that the process might begin with consolidation of some of the supporting industrial contractor activities already under way in a few contracts. While noting some of the issues involved, including "security" due to military missions, and the fact that the first shuttle had yet to fly, he made it clear NASA was planning for a transition, and Congress seemed supportive of the direction in which NASA was going.[13]

Issues of safety were not raised, at least publicly, by NASA management. However, three former astronauts from the Apollo Era did say at a meeting that a lack of funds and insufficient backing by President Carter and Congress were jeopardizing shuttle safety. Charles Duke, Al Worden, and Dick Gordon questioned the quality of the test program "safety margin." A "NASA spokesman" dismissed their views as no better than those of the "average man on the street."[14]

BEGGS AS ADMINISTRATOR

In 1981, James Beggs was appointed Administrator of NASA by President Ronald Reagan. A man who had been a high-ranking NASA executive in the late 1960's, Beggs had served in senior positions in industry and government in the interim. He had worked on the National Academy of Public Administration study of shuttle privatization in 1977. Beggs knew NASA well, along with its difficult political environment. He set two main tasks for his tenure as leader: to move the shuttle into routine operational status and to get the President to endorse the space station.[15] To achieve the latter, he had to make substantial progress on the former, since

he advertised the space station as the "next logical step" after the shuttle. There was pressure from within NASA for a fifth shuttle to add to the fleet, but Beggs regarded that objective as subordinate to the first two.

The push to move more quickly to operations came not just from Beggs. He had allies in his deputy, Hans Mark, who came over to NASA from the Air Force, and General James Abrahamson, who replaced Yardley as Associate Administrator for Space Flight. Moreover, the pressure for privatization from the Reagan Administration was considerable owing to its conservative ideology and the demands of Budget Director John Stockman that NASA justify shuttle expenditures as cost-effective.

Beggs and Mark decided to limitl the testing period for the shuttle. There would be four flights. If all went well, the shuttle would be judged "operational," and the stage would be set for a presidential space station decision. In April 1981, the first shuttle, Columbia, was launched and flew successfully. According to Mark, "we had to fulfill the promise made when the shuttle program started in 1972." What the April flight demonstrated was "that the shuttle was technically successful." But "we still had to prove it was operationally successful. This meant that we had to show we could meet the flight schedules and payload requirements demanded by users of the launch services, provided by the shuttle. We also had to learn to control the operational costs." [16]

Beggs pressured the managers to make the shuttle a viable commercial rocket system as quickly as possible. He remained convinced that a successful shuttle program would build congressional and public support for his efforts to obtain a space station decision. Eventually such a record of success would force the military to cooperate.[17] Beggs was ambivalent about the shuttle. Until he had a space station development program decision, the shuttle was the only big program NASA had. Yet, as it became operational, it was a drain on NASA R&D resources. Beggs searched for a solution to keep NASA in the space business with the space station, but take it out of what he called commercial trucking via the shuttle. Paul Dembling (former NASA General Counsel) said Beggs wanted the shuttle to become self-sufficient. He recalled: "What Jim Beggs said was, 'This (the shuttle) was a big albatross around our neck.... I don't know how to get rid of it and

we shouldn't be keeping it.' That was the dilemma. What do you do with it? How do you get rid of it and not get rid of the support for the Space Program? Because whenever you had a program that didn't capture the imagination of the Congress and the people, you don't get the money." [18]

Privatization became a key strategy by which NASA could hold to the shuttle during the transition to the Space Station Era, while moving out from under Shuttle's more routine requirements. According to Joseph Trento: "Beggs believed that once the shuttles proved themselves in test flights, the imagination of the business community would be ignited and a commercial operator would be found. First, Beggs began searching for private companies to run ground operations at the Kennedy Space Center and then [second] actually operate the shuttle fleet."[19]

In late December, Aviation Week & Space Technology reported that "shuttle management was shifting to operations." It stated that NASA had embarked on a restructuring of its space shuttle management techniques and attitudes to shift the program away from rigid research and development to more flexible operations capability in order to satisfy user demands and counter aggressive competition from the European Ariane Program. "Procedurally we have to make a major effort," declared Abrahamson. "This has been started, and I think it has to be increased to simplify and improve our procedures so that we can have a reliable and repeatable airline-type operation." The magazine said that Beggs and Mark were going to make clear to shuttle personnel that changes were needed now to make the system a commercial success. The operational philosophy had taken a back seat to development needs, and this emphasis would have to change.[20]

THE TEST FLIGHTS

In 1981, the four test flights commenced. In a January news conference, the two astronauts who would fly the first shuttle, Columbia, said they had confidence that the new spaceplane was flightworthy. There had been numerous problems in development, with the main engine and heat-resistant tiles, but the

astronauts, John Young and Robert Crippin, said the problems were in the past. "If there's a vehicle we can have confidence in, it's this one," Young said. "We obviously think it's safe." Young also said he agreed with the NASA decision to forgo a preliminary unmanned test flight, a test which had been the practice in previous manned programs. Such a flight, he said, could have added $500 million to project costs and delayed the program at least a year.[21]

On April 12, space shuttle Columbia soared into the heavens. Two days later it landed successfully to the plaudits of President Reagan, supporters in Congress, and the American people generally. For the first time since the end of the Apollo program, Americans were back in space.

Nevertheless, on the eve of Columbia's next flight, in November, Congressman Edward Boland expressed doubts about the program. Writing in the Washington Post on November 3, Boland admitted that the shuttle gave people a sense of "pride and renewed hope." But: "If the truth were known, never has this nation's space program been beset by more uncertainty, greater disarray and a cloudier future in all its 30-year history." He called shuttle a potential "white elephant" unless turnaround time between flights could be drastically reduced. "That cannot be done without sufficient money to fund enough flights to demonstrate its workability," he wrote. "So the shuttle is caught in a vicious circle, and painful as it is to admit, perhaps its promise as a cheap reusable civilian launch system may never be realized."[22]

Nine days later, Columbia flew the second time and landed successfully. Again, there was praise and elation, and most observers forgot Boland's admonitions. NASA officials, however, understood the problem. They were concerned that the shuttle could not be serviced and returned to space as rapidly as originally hoped. Now at the $10 billion mark in costs since the original program was launched, the shuttle had been sold on the basis of quick-turnaround capabilities. The goal of a two-week turnaround was now giving way to a month between flights. The problem we have, Beggs said, "is simply one of insuring we can service the vehicle in a quick, ready, routine way and make it fly. We will be able to do this, we feel sure, because of that fact that we are, in the four developmental flights, uncovering the various service problems we have." [23]

In February 1982, NASA received a proposal from an investment banking firm to purchase a shuttle for commercial operations. Space Transportation of Princeton, NJ, a subsidiary of William-Sword, Inc., offered a down payment of $200 million to $300 million by early 1983 toward the estimated $1 billion cost of building a fifth shuttle. In return for adding a fifth shuttle to the planned fleet of four vehicles, the company wanted to take over from NASA the marketing of shuttle launching services to commercial and foreign users - - primarily communications. The company sought to use contacts in the White House, including Vice-President George Bush, to pressure NASA.[24]

Asked at a press conference about White House "encouragement" of privatization, Beggs replied that he had been neither encouraged nor discouraged by the White House. He noted that proposals for a shuttle shift to the private sector--or the Air Force or Cosmsat-like operation -- had been "very sketchy," and would have to get "a lot firmer" to be seriously considered.[25]

In March, the third flight of Columbia took place. Again, it was a success. The agency invited eight aerospace companies to send technical observers to Kennedy Space Center to see first-hand the steps involved in readying and launching Columbia. The New York Times noted that privatization ideas were floating around the Capital and quoted Presidential Science Advisor George Keyworth, who was leading an administration review of space policy, that putting shuttle operations in private hands "coincides very well with the Administration's philosophy."[26]

In June, the fourth flight of Shuttle Columbia was launched. When it landed on July 4, Independence Day, President Reagan was on hand. "The fourth landing of the Columbia is the historical equivalent to the driving of the Golden Spike which completed the first transcontinental railroad -- it marks our entrance into a new era. The test flights are over, the groundwork has been laid, now we will move forward to capitalize on the tremendous potential offered by the ultimate frontier of space. Beginning with the next flight, the Columbia and her sister ships will be fully operational and ready to provide economical and routine access to space."[27]

THE SHUTTLE PROCESSING DECISION

The President's congratulations were echoed in Congress. In introducing a concurrent resolution, Senator Alan Cranston (D., Cal.) declared: "Thus far the risk and the cost have been worth it." He noted that "the last test flight of the shuttle is over and the Shuttle is ready to move into an operational phase. Thus, we mark the end of a major research and development effort. The natural question is what's next?"[28]

The answer came on August 5 when Administrator Beggs announced that NASA would employ a space shuttle processing contractor at the Kennedy Space Center, Florida, to handle preparations, launch, landing, and turnaround activities for the space shuttle. Beggs said the contract would result in significant cost savings during the shuttle operational era. It would minimize the interfaces at the launch and landing site and focus clear responsibility on a single contractor. This focus of responsibility would improve flight safety and mission effectiveness, he indicated.

Shuttle processing up to this time, as well as the processing of earlier space vehicles, had been carried out at the launch site by several contractors who supplied flight hardware. The hardware contractors would continue to perform launch services. What was at issue was the work on the ground between flights. There would be a transition period as it was demonstrated that the processing contractor could accomplish the task safely and effectively.[29]

Two congressmen on the House Space Committee expressed concern about the shuttle processing contract. Don Fuqua (D-FL) and Ronnie Flippo (D-AL), alerted prior to the Beggs announcement, had written the NASA Administrator on July 23, 1982. Reflecting muted dissent within NASA, they declared: "we believe flight safety and mission success must be of paramount importance. We are concerned that the shuttle processing contract activities have not been well coordinated within the agency resulting in an apparent split among senior agency officials with regard to their support. The Shuttle Program success to date is in large part due to the dedicated 'team' effort by the agency. We must not allow this team effort to dissolve."[30]

Meanwhile, various firms jockeyed to position themselves for the competition: expected to commence in November with a request for proposals. As firms prepared for the competition, they fell into groups with two contrasting philosophies, views that mirrored differences within NASA.

The first was that processing the space shuttle was a complex, technical operation that could be successful from mission and schedule standpoints only if done by experienced hardware contractors until the maturity of the technological system was assured. The second was that processing the space shuttle was essentially a management task. The shuttle system was mature and design engineering was giving way to sustaining engineering. The incumbent contractors -- Rockwell for the orbiter, Martin Marietta for the external tank and United Space Boosters for the solid rocket boosters -- subscribed to the first philosophy. Boeing, Lockheed, and Grumman believed shuttle processing was a management task and that they were individually capable of taking over this job.[31]

On January 6, 1983, Beggs wrote Congressman Fuqua that KSC would retain control over the processing contractor selected. The development contractors and NASA development centers (Johnson Space Center and Marshall Space Flight Center) would remain deeply involved with the Shuttle Program. Nevertheless, NASA expected that the consolidation of processing activities under a major contractor would lead to substantial financial savings. Beggs minimized the impact of the change on existing relationships, and thus risk potential.[32]

On April 29, the shuttle processing contract bids came in. A team of companies led by Rockwell International Corp., the builder of the space shuttle, and a team led by Lockheed Corp. competed for the contract -- the most lucrative space contract of the decade. The contractor would, in effect, maintain the shuttle. It would service the shuttle orbiter before each flight, put the rocket boosters and shuttle together before launch, and retrieve the booster after launch. The contract could mean $6 billion in revenue during the next 15 years. The first agreement would be for three years with successive three-year options.

While both companies had said they would save on costs, Rockwell, which had serviced the shuttle so far, told NASA that any other company might be too unfamiliar with the shuttle to maintain it safely. Both firms had former astronauts in executive positions and lobbied energetically. The Lockheed team included Grumman, Morton Thiokol, and Pan American World Airways. Rockwell's partners were Boeing, United Airlines, and United Technologies.

Lockheed said safety was not an issue. Lockheed would keep the people who presently worked on the shuttle, hiring them from Rockwell. The difference would be Lockheed's management approach. NASA hoped that naming a single, large contractor would set responsibility for safe and efficient maintenance of the shuttle. Eighteen processing contractors reported to NASA at this time.[33]

On September 7, NASA announced that the Lockheed team had won the contract. The New York Times characterized the decision as a major upset for the team led by Rockwell International. NASA said that it believed Lockheed would maintain stability in employment. It said Lockheed could bring the Shuttle into "an operational mode" more rapidly than Rockwell. NASA pointed out that Lockheed's primary strength was in its management approach, with clear lines of responsibility and authority for each processing function and Lockheed always in charge. Rockwell's horizontal management approach was called "unsuitable for effective and efficient shuttle processing operations." The matrix management in Rockwell's proposal was perceived by NASA's source evaluation board as a weakness. In it, personnel from different companies in the Rockwell team would be intermixed at all levels within the work force, and there would be "extensive utilization of committees in management activities." [34]

PUSHING TOWARD OPERATIONS

In October 1983, the NASA Advisory Council, the agency's highest level group of outside advisors, urged care in NASA's push to operations. It recommended to Administrator Beggs that control of the space shuttle remain in NASA. The shuttle, it said, was a national resource that "is not yet ready" for commercialization. It recommended, however, that within NASA "a new organization be created to manage shuttle operations and utilizations and that, within this new NASA entity, manpower, finances, and facilities be 'fenced,' or confined to serve only these objectives."[35]

Meanwhile, Beggs was working on the President, trying to get him to commit to the space station. In early 1984, in his State of the Union address, Reagan announced that he had decided to develop a space station. Thus, Beggs had fulfilled one of his key objectives -- getting a favorable space station decision. Making the space shuttle operational was another matter.

In June 1984, testifying before the House Space Subcommittee, Beggs said that if NASA continued to improve the shuttle and bring down its cost, by about 1988 or 1989 the agency could turn operations over to a quasi-government or private operator, who could operate it "for profit, or make a little money on it." He said NASA continued to estimate that it would reach a break-even point on shuttle operating costs sometime in the 1989-90 time period. NASA would start examining options for such a turnover in two years and expected to be able to report to Congress in late 1986 that it was prepared to sell the shuttle off, "or more likely, give it away" for private operation by the end of the decade. Before turning the shuttle over, NASA still had to solve some "nagging problems" with the main engine and with certain subsystems -- which he said were "well in hand."[36]

Beggs and other NASA officials testified before Congress in July and August. While the officials varied in their optimism, and some thought there would always be a research and development aspect to the shuttle

due to unexpected problems, they believed operations were on the horizon. All NASA witnesses expressed confidence that shuttle operations would have matured sufficiently by 1989 to provide up to 24 flights a year.

Beggs announced at the hearings the creation of a Shuttle Operations Strategic Planning Group to report by the end of the year on options for privatization. The chair of the subcommittee, Harold Volkmer (D-MO), noted the conflicting nature of NASA's goals. How would it reduce turnaround time and operating costs and at the same time maintain high quality and safety levels. How would NASA keep these goals in balance? Every NASA witness stated emphatically that ensuring product quality and safety was their highest objective and that the agency's goals to reduce turnaround times and operating costs were secondary by comparison.

In its October 1984 report on the hearings, the subcommittee declared as its first finding: "NASA has made considerable progress in establishing long-term goals and objectives for various space shuttle elements which, if successfully accomplished, should bring the space transportation system to full operational maturity by 1989." [37]

Reflecting on the feeling of NASA at this time, Phil Culbertson, Associate Administrator, later said: "Everybody was sort of caught up with the spirit of 'yes ,' we must become operational. And we felt, and I think it is a rational thought, that if we become operational, whatever the term really means, the more responsive we could be to the true customers. The more we could keep things on schedule. We were needing to be competitive. It was clear the greater the launch rate, the more economical the system would be to operate. And the more effectively we drew missions to the shuttle, the less it was going to cost NASA for shuttle missions."[38]

As the space station program got underway, and as new starts in space applications and space science looked for funds, the R&D initiatives bumped into the space shuttle. The space shuttle was increasingly seen as a barrier to NASA's true purpose. Senator Slade Gorton (R-WA)), chairman of the Senate Space Subcommittee, declared in October 1985 that the ongoing shuttle costs were a "tremendous drain" on

NASA's R&D mission. He called for "serious consideration" of transfer of shuttle operations from NASA to a commercial entitiy.[39]

At the same time, the shuttle was the only program NASA had to bring space the public visibility needed to attract huge budgets As the shuttle appeared to become more routine (and thus less exciting), NASA took more risks to retain public attention. In the Apollo era and up to this point in the shuttle program, astronauts with "the right stuff" were defined primarily as test pilots, usually with robust military test flight experience. The idea of flying private citizens on the space shuttle did not appeal to many in NASA but Beggs was convinced that it was just the kind of publicity the program needed. He wanted to show that the shuttle made spaceflight an ordinary activity. He wanted to prove that the shuttle was making progress and was "operational."[40] As a consequence, it was decided to allow "citizen astronauts" to fly. The first was Senator Jake Garn (R-Utah), a member of the appropriations subcommittee that handled NASA, in March 1983. Then came Prince Sultan Salman Al-Saud, a Saudi Arabian, presumably there to deploy an Arabian satellite, on June 17. In December, Rep. Bill Nelson (D-Florida), chairman of the House Subcommittee on Space Science and Applications, flew on a shuttle.

Beneath the surface bravado about moving toward routine operations, there were concerns. The Deputy Administrator, Hans Mark, left NASA in mid 1984. Prior to leaving, he had ordered that all solid rocket mctor seals and joints, including O-rings, which had charred in some of the shuttle flights, be reviewed. He had intended a higher level review, but left before that could be done. A review was carried out, but on the level of Marshall Space Flight Center and the contractor, Morton Thiokol. The O-ring issue was a risk, but was deemed "acceptable."[41] Taken more seriously were problems associated with the processing work of Lockheed. In March 1985, a work platform fell in the orbiter processing facility, damaging the orbiter Discovery and injuring a workman. NASA Administrator Beggs reacted strongly to the incident and in May, following an internal investigation, Lockheed reassigned the top three officers of its Lockheed Space Operations Co. at Kennedy Space Center, including the Chief Executive Officer. The corporation said the moves were an

attempt to provide " a different management approach" to space shuttle processing. NASA indicated it had no plans to recompete the contract. Ironically, it had only been a short time before that Lockheed had won the contract because of its management approach.[42]

CHALLENGER

On January 28, 1985 the space shuttle Challenger exploded shortly after take-off. The disaster took the lives of seven astronauts, including teacher-astronaut Christa McAuliffe. With Beggs incapable of serving as Administrator because of an indictment related to his work in industry, a charge later proved false, leadership fell to his deputy, William Graham. Graham was new to NASA, forced on the agency by the Reagan White House, and without internal support. President Reagan further diminished NASA's influence over immediate events by quickly appointing what became known as the Rogers Commission to investigate the tragedy. Wounded, NASA looked for someone to provide a sense of direction.

THE LONG RETURN TO FLIGHT

It was not until September 29, 1988, thirty-two months after Challenger exploded, that the space shuttle Discovery flew successfully, returning NASA and the nation to space. In between, NASA labored at repairs to the shuttle and to its image. Risk and recovery were mixed, and NASA had only partial control over the pace and direction of the recovery process.

With NASA leadership in disarray, Rear Admiral Richard Truly, a former astronaut, agreed to join NASA as Associate Administrator for Space Flight. Named February 20, 1986, he was determined to get NASA flying again as soon as possible, while upgrading the agency's capacity to deal with the inherent risks of space. Working furiously to familiarize himself with the issues, he reported in late March to an audience of 1000 at the Johnson Space Center and thousands more who watched on closed-circuit television at other NASA centers. He laid out a technical strategy for recovery promising to "correct mistakes we may have made

in the past." He declared, however, that "flying in space is a bold business. We cannot print enough money to make it totally risk-free."[43]

At this point, Truly believed it would take about eighteen months to make the necessary corrections and launch the next shuttle. That it wound up taking two and a half years was due to the role outside reviewers played in decision making. For example, by this time it was clear that the solid rocket motor O-ring joint would have to be redesigned and Truly directed the Marshall Space Flight Center to take the lead in redesign.

But the Rogers Commission inquiry was underway, and the Commission communicated privately that the members wanted "an independent panel of experts to approve the new joint."[44] This meant NASA would have some group of experts looking over its shoulder after the Rogers Commission completed its work, and throughout the recovery process. There was little Truly could do but go along. In May, he announced an independent body would be created and would report directly to himself. It would work with NASA in overseeing the joint-redesign as well as integrating the Rogers Commission findings into NASA's plans for recovery.

Also in May, James Fletcher agreed to return to NASA as Administrator, thus ending the vacuum at the top of the agency. The man who had gotten Nixon to agree to launch the shuttle program fourteen years earlier, Fletcher was thoroughly familiar with the space shuttle, and his appointment had a salutary affect on agency morale. He and Truly were in a position to move the agency ahead again.

On June 9, the Rogers Commission issued its report. It said that the accident was caused by a failure in the O-rings sealing the joints between the two lower segments of the right solid motor. It went beyond the technical finding to criticizing management. "The decision to launch the Challenger was flawed," said the report. "Those who made that decision were unaware of the recent history of problems concerning the O-rings and the joint and were unaware of the initial written recommendation of the contractor advising against the launch at temperatures below 53 degrees Fahrenheit and the continuing opposition of the engineers at

Thiokol after the management reversed its position. They did not have a clear understanding of Rockwell's concern that it was not safe to launch because of ice on the pad. If the decision makers had known all the facts, it is highly unlikely that they would have decided to launch 51-L [the name of the flight] on January 28, 1986."

The Report called Challenger an "accident rooted in history." The joint was faulty to begin with, and NASA and its contractor "first failed to recognize it as a problem, then failed to fix it, and finally treated it as an acceptable flight risk." It called the flight schedule "unrelenting," but might have been manageable had NASA "insisted on the exactingly thorough procedures that were its hallmark during the Apollo program." That not being the case, the flight schedule was "overambitious." It already had been scaled back from an early plan for one mission a week. "In 1985, NASA published a projection calling for an annual rate of 24 flights by 1990," and reaching that rate was not likely. "The capacities of the system were strained by the modest nine-mission rate of 1985," and "NASA would have not been able to accomplish the 15 flights for 1986."

The Report made a number of recommendations having to do with design, independent oversight, the creation of an Office of Safety, Reliability and Quality Assurance, and strengthening of the Headquarters' shuttle management vis-à-vis that at the Centers. It called for more astronauts in management, improved communication, and a "flight rate consistent with (NASA's) resources." No longer should the nation rely on the shuttle as its principal space launch capability. That reliance "created a relentless pressure on NASA to increase the flight rate."[45]

On June 13 President Reagan directed NASA to implement the recommendations "as soon as possible." Meanwhile, the National Academy of Sciences-National Research Council constituted a panel of distinguished technical experts, led by the former National Science Foundation director H. Guford Stever, to be the independent body advising NASA in its recovery program. On July 14, Fletcher wrote Reagan providing a plan for responding to the Rogers Commission's recommendations. Needless to say, the drive to move the shuttle toward privatization was on hold.

Most NASA attention went of necessity to redesign of the defective joint. The decision to be made was whether the existing design could be modified or whether an entirely new design was required. The latter would add enormously to cost and time. "Minimum necessary change" -- that was the option Truly favored. The Stever panel did not disagree, but aimed at safety first beyond any other value. Truly was in the position of trying to balance a complex set of considerations: safety, time, money, user needs, feasibility, etc. The result was considerable contention, many tests and retests, and constant pressure on NASA to go the extra mile in pursuit of safety, and then beyond. The Rogers Commission had criticized NASA for its "silent safety program." The Stever panel was anything but silent.[46]

As the technical work progressed on the O-ring joint and other areas of work recommended by the Rogers Commission, Truly and Fletcher also discussed the question of management reform. The Rogers Commission found NASA decision-making flawed. There had been lack of communication across centers and between centers and headquarters. Headquarters had not even known about the center-contractor debate over whether or not to fly the night before Challenger was launched. In his March "return to flight" speech, Truly said he would take a hard look at management. In May, Fletcher, just appointed Administrator, asked Sam Phillips, former Apollo manager, to conduct a thorough management assessment covering all NASA. In June, Truly requested Robert Crippin, an astronaut, to look specifically at shuttle management. The two studies were complementary and yielded a similar conclusion, where shuttle was concerned: there had to be more topside control.

Using Apollo as the model, on November 5, Truly restructured shuttle management. He replaced the "lead center" concept in which Johnson Space Center was in charge, with a headquarters approach. There would be a strong shuttle director in headquarters reporting to Truly The director would have two deputies responsible for overseeing work at the centers. In line with another management recommendation of the Rogers Commission, Truly also began to move astronauts (like Truly) into managerial positions. Crippin would

be one of these individuals. The new shuttle director, however, was a seasoned technical manager, Arnold Aldrich, thoroughly familiar with shuttle but not tarred as so many NASA officials had been by Challenger.

The Rogers Commission had not dealt specifically with the Lockheed servicing contract, much less privatization, as direct factors contributing to the accident. But in noting the "relentless pressure"... "to increase the launch rate," it had come close. The media had reported on various problems associated with shuttle processing during the Rogers Commission investigation, as it conducted its own inquiry to uncover weaknesses in NASA's management. In February 1986, The New York Times reported that the previous November a segment of a solid rocket had been damaged, and another accident had occurred the previous March, when a large piece of equipment was dropped on the space shuttle Discovery, causing $200,000 in damages and injury to a worker.

The Times noted that a NASA investigation of the March accident had uncovered inexperienced personnel at Kennedy who were careless and unmotivated. The general attitude of many was: "I was doing something else at the time," "I only look at what I have responsibility for," and "that's not part of my job." According to The New York Times, a former employee stated: "Among the peons, there's an attitude of only wanting to cover your butt."[47]

The Rogers Commission found that Challenger's solid rockets were not examined by any NASA processing engineer in the 38 days the shuttle sat on the launch pad prior to January 28. Once moved to the pad, the shuttle was considered a structurally safe vehicle, not true as it turned out. Moreover, the number of NASA quality control inspectors had been going down as the number of flights went up. Lockheed's number had increased, however, and NASA had presumed Lockheed had filled the gap .[48]

One of the early decisions Fletcher and Truly had to make in NASA's recovery from the Challenger disaster was whether to renew Lockheed's contract. They decided to keep Lockheed, but to conduct a thorough review as part of the overall evaluations of shuttle's management. Truly appointed a Shuttle

Processing Contract Review Team, chaired by Roy Estess, deputy director of the National Space Technology Laboratories, Mississippi.

While the Estess panel conducted its study, the Crippin review raised a number of concerns about shuttle processing. Also, in testimony before Congress, shuttle development contractors commented critically. A member of the Rogers Commission was also quoted by Aviation Week & Space Technology that some of the pre-accident procedures "were an accident waiting to happen." He was referring primarily to overtime-induced stress during processing and countdown cycles and to paperwork found to be deficient. The director of Kennedy Space Center, Lt. Gen. Forrest Mc Cartney, who assumed that post October 1, 1986, said the criticized practices would be history under his regime, which would emphasize safety and success over schedule.

The Estess panel reported in March 1987. While finding much to criticize, it nevertheless said that the current Shuttle Processing Contract arrangements should be retained and strengthened. The bottom line was that total change at this point would be too disruptive; it was easier to try to fix the deficiencies. For example, the panel recommended more emphasis on quality control and engineering and closer NASA supervision. Among the negative findings was the widespread view at Kennedy that "the transition to the SPC was traumatic and NASA personnel were unsure of their roles." Many interviewed by the Estess panel said that the shuttle was not operationally mature and accountability was weakened in transition to the SPC concept.[49] Fletcher informed Congress and the White House of the Estess panel findings. NASA followed-up, taking actions to augment staff in quality assurance and engineering, increasing emphasis on launch support contracts with hardware manufacturers, and stressing more thorough technical documentation.[50]

In early August, one and one-half years after the Challenger accident, NASA powered up the orbiter Discovery to begin the processing cycle for a return to flight.[51] NASA hoped for a launch in February 1988. But there was a malfunction during a December 1987 test of a rocket nozzle. The agency delayed the scheduled launch until late summer. Asked in March 1988 when the next shuttle would fly, Fletcher said, "We

will fly only when we are ready. And readiness means that the Shuttle will fly only when it's safe as we can make it".[52]

In the same month, a second National Academy of Sciences-National Research Council committee, appointed November, 1986, reported. Headed by Alton Slay, a retired general and former head of the U.S. Air Force Systems Command, this panel had been asked to focus on risk management as it related to the shuttle. Slay stated: "Our central finding is that while NASA has the basic organizational elements for assessing and managing risks, the arrangement is a complex mosaic of numerous review boards and safety organizations which yields a fragmented picture." Moreover, NASA's current operation relied too heavily on "qualitative rationales and subjective judgments." Slay said the panel was not calling on NASA to replace professional judgment with computers. It was asking NASA to supplement engineering judgment with modern statistical analysis, such as a technique called probabilistic risk assessment (PRA)." Nevertheless, the panel believed the shuttle was safer today than at the January 1986 launch, and the panel had found "no show-stoppers" to prevent the next shuttle from flying.[53]

In June, NASA conducted a full-scale integrated flight simulation to validate its launch procedure. One person was made clearly responsible for each milestone decision leading to the launch of Discovery. Three hundred members of the launch team took part in the exercise. For the first time, top-level decision makers were involved. Robert Crippin, deputy director of the shuttle program, would make the final decision to launch or not launch.[54]

In August, the five astronauts chosen for the flight, possessing strong shuttle experience, met with reporters. "It's going to represent a turnaround in our spirit," said marine Lieutenant Colonel David Hilmens, flight engineer. "It's almost a given that it has to come off, has to come off smoothly." The crew was more than ready; it had been in training for two years for a mission involving a brief, four-day sojourn with few complex tasks.[55]

In early September, the Stever Panel declared it was satisfied no safety concerns stood in the way of launching the first mission since Challenger. NASA had by now done virtually everything it felt it could do technically: hundreds of modifications in the complex shuttle involving O-rings, rockets, and orbiter. It had also made a host of administrative changes to clarify who made what decisions, strengthen headquarters control, and facilitate communication. It had set up a new central safety office to improve risk assessment techniques, and augment engineering judgment with statistical methods. It had sought to evoke a "safety first" attitude throughout the organization. If anyone saw any problems, they were expected to report them immediately. With all that, there were still "1,514 elements" on the shuttle "whose failure could result in loss of ship and crew." Still, virtually everyone associated with the program believed Discovery's flight would be safer than any before or after. "It's the flight you want to put your mother on," said one NASA official.[56]

Far from the previous rhetoric of the routine, NASA now called this launch a "test flight." On September 26, Truly said, "we will always have to treat it [the shuttle] like a R&D test program, even many years into the future. I don't think calling it operational fooled anybody within the program....it was a signal to the public that shouldn't have been sent and I'm sorry it was." [57]

Three days later, September 26, 1988, the Space Shuttle Discovery soared from its launch-pad. The moment of time after launch at which Challenger had exploded catastrophically came and went, and Discovery moved into orbit. Four days later, the shuttle landed safely, on schedule. After 32 months of turmoil and anxiety, the United States space program was coming back.

Trying to Return to Normalcy

On December 2, the space shuttle Atlantis flew. Landing December 6, it marked a second successful flight. Amidst all the jubilation and relief, however, there was a new wariness. NASA was back in space, but with a heavy realization that the risks were a lot greater than it had thought before Challenger. The best statistical analysis NASA had now was loss of one shuttle every 78 launches. The Stever Panel disbanded

December 1988, but Stever in his farewell comments, warned: "Success breeds confidence, and that's what you want, but it can also threaten you with complacency."[58] Fletcher added to the symbolism that a milestone had come with the return to flight. Retiring for the second time from NASA, the Administrator held a press conference. He said he did not believe another Challenger would occur for some time, but people had to be prepared for such an event given the realities of risk in space. If and when another disaster came, he hoped it would not again ground the shuttle for almost three years. He also scored a parting shot with the Rogers Commission for its "adversarial" investigation. It was "like a court trial," he charged.[59]

Admiral Richard Truly, widely credited with leading NASA's recovery after Shuttle, was selected by George Bush, who had become President in January, to be Fletcher's successor as Administrator. Truly was now responsible for an agency chastened from the criticisms it received after Challenger. However, it was also an agency that President Reagan had supported verbally and through his decision to replace Challenger with a fourth shuttle. The President and Congress had also augmented NASA's budget, perhaps in recognition that the agency needed help to recover.

President Bush was a space enthusiast, like Reagan. In July, celebrating the 20th anniversary of the Apollo moon-landing, Bush proclaimed the long-range goal of returning to the Moon and going onward to Mars. Bush, who called himself the "environmental president," also endorsed a giant remote sensing program of NASA called Mission to Planet Earth. Finally, Bush said he would back the space station, whose development had been delayed because of congressional opposition over Challenger. He appointed Dan Quayle, Vice-President, to take the lead on administration space policy through his chairmanship of the interagency National Aeronautics and Space Council.

Truly was conscious that much that NASA wished to do, including the space station, was entirely dependent on the space shuttle. He was aware of a study by the Congressional Office of Technology Assessment which said it was "statistically likely" that a shuttle would be lost before the space station was fully assembled, given the large number of shuttle flights it would take to build the station. He also was cognizant

that the risk of stopping the space program in its tracks could be reduced by acquisition of a fifth shuttle .[60] Truly's top priority as he took over as NASA Administrator was making the Shuttle program more robust-- a course that included getting a fifth orbiter.

Even without the pressure of the space station-- over which the administration and Congress continued to fight--there was a huge backlog of military and scientific payloads whose launch had been much postponed during the Challenger hiatus. These included NASA's most prominent science mission, the Hubble Space Telescope. Also, the absence of flights worsened shuttle costs, since a huge workforce and infrastructure had to be maintained whether or not the flights took place. The fewer flights, the more costly any one flight.

In September 1989, NASA extended the Lockheed shuttle processing contract three more years. In doing so, the agency indicated it wished to accelerate the processing cycle without compromising safety. NASA would have six flights in 1989, the same number as in 1985. That number meant a given flight would cost $250 million. The agency wanted to move up to nine flights in 1990.

To do that the number of processing days had to go from 65- 79 to 44-51, or lower. In May, NASA and Lockheed started searching for ways to save time without reducing safety. The number of required inspections at this point was gigantic --213,000. By November, NASA and its contractor pared these to 173,000. Norman Parmet, a member of NASA's Aerospace Safety Advisory Panel, said members of his group believed that some of the processing procedures at Kennedy after the Shuttle accident were too stringent, and he supported the elimination of those which were unnecessary.[61]

Unfortunately, in 1990, a string of mishaps at Kennedy served to derail NASA's ambitions to significantly and safely speed-up the schedule. These included: a number of hydrogen fuel leaks which grounded the effort from mid-May until early October; a misprogrammed flight computer discovered by a shuttle crew while in orbit; a payload bay door bent when it was struck by an overhead crane; leaks in the coolant systems of two different shuttles; a seriously damaged fuel cell costing $3 million to fix; and most

embarrassingly, a nine-foot-long beam, part of a work platform, left inside an engine compartment just three days before a flight.[62]

NASA sent a team to Kennedy to investigate the sequence of processing problems. But these were overshadowed by discovery, shortly after launch, that the multi-billion dollar Space Telescope had a misshapen lens, and hence, blurred vision. Given the hype and ballyhoo the telescope had received before it was launched by a shuttle, the Hubble trouble was a public relations, as well as scientific, nightmare for NASA.

Was NASA slipping again? Was it trying to do too much, too soon? While a future Hubble repair mission could alleviate the immediate problems, a number of questions were raised about the agency's capacity and direction in general. NASA faced its first crisis in confidence since Challenger. The Bush Administration appointed a blue-ribbon panel, headed by aerospace executive Norman Augustine, to assess the space program and recommend future strategies.

In December 1990, the Augustine Committee produced a thoughtful document that covered NASA as a whole and ranged broadly. It had much to say about the shuttle, its privatization, and the issue of risk.

It called the shuttle a "great technical achievement" with "impressive and unique capabilities" that was also "a complex system that is expensive to operate and whose emergence from developmental status had not yet taken place." While the panel did not believe the shuttle was ready for transfer to private control, given its "quasi-developmental" status, it did believe NASA had to manage a long-term transition from R&D to operations. Operations, however, did not imply "routine" in this case. The shuttle "in no way simulates the functioning of commercial airlines with which it is sometimes (inadvisably) compared," the Augustine group said. Quoting from a 1988 National Academy of Public Administration report, the Panel saw the shuttle increasingly "driven by operational issues -- turnaround time between flights, manifesting, retrofitting of design changes for safety, cost or payload capability purposes, logistics, training of basic and science crew members, and so on. These are <u>not</u> the basic work of research and development...."

The Augustine Panel called for a separation of shuttle from R&D activities in NASA , with shuttle headed by a new headquarters Associate Administrator for Space Flight Operations. It also recommended moving most of the shuttle technical work from the Johnson Spacecraft Center at Houston (with its development orientation) to the operationally inclined Kennedy Space Center). In managing the transfer from development to operations, NASA could save costs by eliminating expensive legacies from shuttle's development and Challenger past, including "excessive layers of management."

The panel had much to say about other programs. In general, it was a positive document that set a direction for missions from Earth and to Earth. It did not recommend a fifth orbiter, much to Truly's dismay. It did call for a hefty increase in NASA's budget to pay for its recommendations -- 10% each year for the rest of the decade, reaching $30 billion in 1990 dollars by 2000.[63]

Truly could go along with much of what he read, and certainly liked the comments about more money. Unfortunately, Bush and Congress in 1990 reached a budget agreement aimed at cutting the deficit, which had become gargantuan. This agreement precluded the 10% increases recommended for NASA. Instead, NASA found its ambitions steadily squeezed. Its budget stood at $12.2 billion in FY 1990 and prospects for the $30 billion budget in 2000 that the Augustine Panel proposed were rendered moot. Given the need to augment new R&D efforts, such as Mission to Planet Earth, space station, and other programs, the argument for consolidating shuttle expenditures in an "operations-like" division gained added salience.

Truly decided in 1991 to begin by upgrading Kennedy Space Center in the overall scheme of shuttle management. In doing so, he moved Robert Crippin, the deputy space shuttle manager, to the directorship of the Kennedy Space Center, replacing Forest Mc Cartney. Crippin assumed his new post January 1, 1992 and immediately warned that the Shuttle Program had to downsize. He said that as many as 20% of the 25,000 government and contractor shuttle jobs, nationwide, would go over the ensuing five years. He believed that attrition would take care of most of the job cuts, and that Kennedy, given an enhanced shuttle role vis-à-vis other centers, would remain relatively stable.[64]

GOLDIN TAKES OVER

Truly was unhappy with White House policies and with Dan Qualye looking over his shoulder. Relations soured, and President Bush fired Truly in early 1992, replacing him on April 1 with Dan Goldin, a TRW executive with considerable experience in managing classified space programs.

Goldin came to NASA convinced the agency needed a shaking up, basic reform, if it were to accomplish all the missions on its plate and garner more. He proposed a new culture at NASA, geared to technology that was "smaller, faster, cheaper." In January, 1993 President Bill Clinton came into office and decided to retain Goldin, a registered democrat. Clinton wanted a solid space program, and gave it his signature by linking Russia to the space station. Clinton also wanted to hold down government spending. Goldin's smaller, faster, cheaper mantra was perfect in gaining credibility with Clinton. Al Gore inherited Quayle's mantle of White House space czar, although the National Aeronautics of Space Council was abolished. Gore was also given the lead for a National Performance Review of the Executive Branch aimed at making government more efficient. NASA became the "poster child" for reinvention, with Gore the cheerleader and Goldin the implementor.

In December 1993, NASA accomplished the repair of the Hubble Telescope, an unprecedented display of extra-vehicular activity by astronauts. The mission was deemed an outstanding success in early 1994 when pictures came back from a telescope whose vision was no longer impaired. NASA received plaudits and favorable publicity the like of which it had not seen since Apollo. Goldin and other leaders basked briefly in the glory.

Hubble could not have been repaired without the shuttle, which performed magnificently as a work station. And there would not be a space station without the shuttle. Hence, the space shuttle remained what it had been since 1972 -- the centerpiece of all manned spaceflight at NASA. Despite the successful performance of the shuttle Endeavor during Hubble repair, controversy swirled over the future of the shuttle. Much of the concern was over risk. And risk had to do with budgets.

BUDGETS AND SAFETY

William Broad, writing in The New York Times, in March 1994 pointed out that funding for the space shuttle had been going down steadily, touching off a debate over whether NASA "was being forced to cut corners and raise the risk that its temperamental spaceship might break down or blow up." The budget for shuttle went from $4.0 billion in FY 1992 to $3.8 billion in FY1993 to $3.6 billion in FY 1994. In the proposed 1995 budget that President Clinton had recently presented to Congress, the funds would drop to $3.3 billion. Goldin, who had won praise as a "proponent of streamlining," told Congress that the budget could fall no further without raising the risk of calamity. "This is it, " he said. "We can't get any closer to the bone." Goldin added: "Based on what we know today, we cannot cut human space flight any further without impacting on safety."

Broad pointed out that a lot of experts were agreeing with Goldin. He noted that worries about booster rockets were being succeeded by new questions about a system that had long been considered one of the spaceship's riskiest: the high-pressure pumps that fed liquid hydrogen to combustion chambers for explosive burning. NASA was cutting cost by reducing inspection of shuttle parts and repair procedures. In the post-Challenger period, inspections had "skyrocketed," with any given action checked seven times, and some two million signatures and approvals needed before any shuttle left the launch pad. To avoid all the checking and rechecking, NASA was trying to go to a system in which the people doing the work took more responsibility for quality control. NASA spokesmen claimed that the new system was not going to do anything that would endanger astronaut lives, but a lot of people within and outside NASA were getting worried, Broad wrote. [65]

NASA's goal in 1992 had been to cut the shuttle budget three percent per year for five years. The cuts had been steeper, five percent per year, and the pressure to cut still further from the Clinton Administration and Congress was unyielding. NASA was protecting the space station budget and squeezing

other programs, the shuttle included. In September 1994, Goldin ordered a review to determine the shuttle's health after budget cutbacks and identify possible additional savings. NASA's Associate Administrator for Space Flight, Jeremiah Pearson, was in charge of the review. Under him was Bryan O'Connor, Shuttle Program Director at Headquarters. O'Connor said thirteen teams at NASA field centers across the nation were examining jobs, procedures and requirements to improve efficiency. He stated that the teams were considering "every type of technician, every type of engineer, how many of them there are, why we have them, what kind of requirements they're fulfilling, are those still valid requirements, are there shortages?" Both men emphasized safety was still the priority.[66]

In mid-November, however, Pearson resigned abruptly, and "sources" said that he did so "in part...because of concern about the rapid pace of current efforts to cut costs across the shuttle program." [67]

PROPOSING PRIVATIZATION

Goldin, on November 23, turned to Christopher Kraft, former director of the Johnson Space Center and Apollo veteran, and asked him to lead an independent panel to review the way the agency ran the Space Shuttle Program. The signals Goldin had from Clinton and Congress continued to be grim on future NASA budgets. How could more be cut from the programs safely? Many managers were saying that there was no way to take additional money from the shuttle budget and still maintain a flight rate intended to be six or seven flights a year, essential to construct the space station on a reasonable schedule, without radical change in the program.

Goldin made it clear to Kraft that his panel could think in radical ways. Space News reported one option the Kraft panel was expected to consider was "turning more responsibility over to shuttle contractors and reducing NASA's direct involvement in day-to-day shuttle management."[68]

As 1995 began, a Republican majority, elected the previous November, settled into command of the House and Senate. The Republican "Contract for America" called for a balanced budget. Clinton said he had

gotten the election's message, would work toward a balanced budget, but wished to protect certain priorities. These priorities did not include NASA. He directed Goldin to cut $5 billion from its five-year projected budget. Such a cut meant NASA's overall budget would drop from $14.3 billion in FY 1995 to $13.2 billion in FY 2000, a draconian reduction considering inflation.

In February, Kraft delivered his panel's report. Kraft said that the shuttle should no longer be regarded as experimental and that NASA should not only put routine shuttle processing but also flight operations into the hands of a single lead private contractor. The Kraft report found an "overabundance of engineers" that had created excessive requirements for hardware analysis. It charged that replacement, tests and checkouts between flights required a total of 750,000 "labor hours" to process each shuttle. Moreover, as a result of the Challenger accident, managers, engineers and business executives were reluctant to make decisions that involved risk because of fear of persecution. Instead, they had shielded themselves behind a safety organization of as many as 4000 people, costing more than $350 million per year. And yet, the panel said, all this "may make the vehicle less safe because of the lack of individual responsibility."[69]

Reaction was mixed to the Kraft report. Testifying in March, Goldin said he was committed to reducing shuttle costs further. He said safety was a "huge weight" on NASA's shoulders, but people should not hide behind safety -- apparent safety -- to protect budgets.[70] He agreed with Kraft and felt that having too many people sign off on flight readiness "represents a threat" to safety, rather than a guarantee of it. " I want to hold one human being responsible," he declared. That person was Pearson's replacement as Associate Administrator for SpaceFlight, J. Wayne Littles. House Speaker Newt Gingrich and some others in Congress wanted to move faster with privatization, such as the Chair of the House Science Committee, Rep. Robert Walker (R-PA). But John Pike of the Federation of American Scientists called the Kraft Report "close to hallucinatory." Seeing the Kraft recommendations as a recipe for dismantling the safety and quality assurance mechanism set in place after Challenger, he predicted that the proposals someday would be considered "the turning point that led to the next shuttle accident."[71]

Bryan O'Connor, shuttle chief, said he understood that radical restructuring was the only way to achieve the drastic level of cost reduction the White House had called for in January. Safety was still the shuttle's top priority, but times had changed. After Challenger, he noted the mood in Congress and elsewhere was to do whatever it took to push shuttle safety risk as low as possible. But now the mood was not safe "as possible," but safe "as practical." NASA had now to deal with the risk/cost trade-offs. More emphasis on one side meant less attention on the other. He did note that a recent study by an outside consultant showed that improvements in the shuttle after Challenger meant the risk of catastrophe had gone from one in 78 flights to one in 100 or maybe even 120. At the same time, O'Connor did worry that moving too fast in a privatization transition could be a problem.[72]

Jeffrey Carr, Johnson Space Center Director of Public Affairs, pointed out that the Kraft Panel included not only the respected Kraft, but six top retired NASA and industry officials. These included Frank Borman, retired astronaut and former Chief Executive Officer of Eastern Airlines, and retired senior executives from Rockwell, Thiokol, DOD, and various NASA Centers. "How can you not take seriously recommendations from a panel of experts like this?" he asked.[73]

THE PRIVATIZATION DECISION

Goldin said that the decision would be made in May on privatization, as part of an overall look at how to meet the President's objectives. The NASA Administrator was getting information from various sources along with suggestions from the Kraft Panel. Interviewed at the end of March, Goldin said that if the agency decided to go with a single contractor to run the program, such a step would be taken "in parallel" with ongoing agency efforts to develop a reusable launch vehicle (RLV) as a shuttle replacement. He said that "we're considering bringing a contractor in as the prime contractor on the shuttle [and] giving that contractor about a year or two to try and develop an understanding and see if it's possible to privatize."[74]

In May, Goldin accepted the Kraft Panel's recommendation to contract out space shuttle operations as a cost-saving move that could be a significant first step toward privatizing the shuttle entirely. Wayne Littles, the head of the Office of SpaceFlight said he believed "that with time we will have an operational program that will be an operational block, if you will on the management chart, and on the operations block will be both the shuttle and the space station."[75]

In June, NASA prepared to issue a call for proposals to industry to see who would actually be the prime contractor. Most observers believed the single contractor would be either Lockheed or Rockwell -- since they were already the dominant companies in the Shuttle Program. When Lockheed won the ground processing contract in 1983, it took work away from Rockwell, the prime contractor that built the orbiter. Now the two firms were expected to compete for an even larger prize.

Goldin put a positive face on the proposed action. "We're going to be a lot more flexible, a lot more mobile. I think it's going to strengthen our case for starting new programs".[76] NASA would be a much leaner organization, but would it be safer? The agency had 26,000 employees in 1991, and was down to 21,000 in 1995.

The privatization move would drastically reduce the number of people who were required to sign off on the flight readiness of various shuttle components before each launch. That aspect alarmed critics who said flight safety would be jeopardized at a time when shuttle managers were struggling to meet a demanding launch schedule, geared to working with other nations, including Russia, to build a space station. The schedule now called for 27 flights between 1997 and 2002.

In August, Rockwell and Lockheed announced they would not compete for the new prize. Instead, they would form a partnership, a company called United Space Alliance (USA). NASA had expected to ask industry to bid competitively. But these two companies presented the agency with a "preemptive strike." Lockheed Martin, based in Bethesda, Maryland, provided the shuttle's external tank and launch services. It also provided ground processing, landing, and retrieval services at Kennedy and support operations at JSC. For its

part, Rockwell produced the orbiter vehicles, systems and engines, as well as providing payload integration, logistics, and astronaut training. Each company employed about 10,000 workers through shuttle-related contracts. They had $2 billion of the shuttle business, then running at about $3.2 billion. Hence, when they made their move to form a 50-50 joint venture, they presented other possible competitors, as well as NASA, with a fait accompli.

On November 7, NASA announced that there would be no competitive bids on the shuttle contract. NASA would pursue a negotiated agreement with United Space Alliance. In announcing the decision, Goldin said going sole-source was in the best interest not only of honoring U.S. commitments to other nations in commencing space station construction, but also in the interest of safety. "There was no other company that could possibly meet our safety, manifest, and schedule requirements," said Goldin, "We have two experienced companies that clearly understand how to operate the shuttle safely. There's no new contractor or work force to train." He said the contract would provide incentives to maintain safety and schedule while saving money.[77]

Kraft called the decision "very wise." He declared: "I think the vehicle will not only be as safe as it has ever been, I think it has a chance of being even more safe." Under the contract, NASA would retain oversight over shuttle payloads, flight crews, and ground control and launch decisions.[78]

Congress was less enthusiastic. Legislative rules gave it thirty days to veto a sole-source decision by NASA. Rep. James Sensenbrenner, Chairman of the House Science and Aeronautics Subcommittee, with direct oversight of NASA, expressed anger at the short notice his committee received prior to Goldin's sole-source decision. He expressed skepticism that USA would lower costs and achieve necessary safety. Littles responded that safety would be "paramount" and NASA would hold USA accountable through fee structure for safety, fulfilling NASA's flight manifest, and cutting costs, in that order.

At the end of November, Sensenbrenner made Goldin testify before his subcommittee under oath on the decision. The NASA Administrator said he had asked the agency's Aerospace Safety Advisory Panel, an independent body, to review the agency's plan to move to a single contractor. He admitted the merger

affected NASA's bargaining power with industry, but, "You have to deal with the world as it is presented to you." He promised that the negotiations would not be a "love fest," and he was prepared to break off negotiations if USA did not cooperate. He would find the budget savings sought another way. Goldin said going sole source would "maximize safety," and the Chairman of the Aerospace Safety Advisory Panel said on December 1 that there was "no reason why safety should be compromised by giving the shuttle's operation to a single contractor."

The subcommittee gave tacit approval by allowing the deadline to slip by without action.[79]

SHUTTLE'S DIRECTOR RESIGNS

At the beginning of 1996, Goldin moved to implement a number of organizational changes. These followed from a NASA plan for adapting to the President's proposed budget cuts. The reorganization included a substantial shift of responsibility to the Centers from Headquarters. While all of NASA would shrink, Goldin felt Headquarters could take an even larger percentage reduction than the Centers. One of the changes would move the locus of shuttle management from Washington to Johnson Space Center. This meant that the shuttle manager in Houston would report to the director of the Johnson Space Center instead of O'Connor. It would also place KSC and Marshall Space Flight Center in a reporting role to a peer-center.

O'Connor complained bitterly about the management changes. He reminded his superiors that one of the reforms following Challenger was to strengthen Headquarters' role in the shuttle because of the bureaucratic rivalries at the Center-level that hurt communication. Goldin delayed action on the reorganization and asked senior managers in the agency to determine the seriousness of O'Connor's concerns. They reaffirmed their support of the proposed changes. Goldin made the reorganization official February 2, and O'Connor announced his resignation the same day.[80]

While O'Connor said he was leaving "to pursue other interests," no one took this statement seriously. O'Connor was considered one of the brightest stars in NASA management, an ex-astronaut with unusual

executive ability and credibility. Goldin downplayed the resignation, expressing "trust" in the Center directors. But the resignation sent "shock waves" through NASA and was interpreted by many as reflecting on safety questions as much as bureaucratic status and hierarchy. A congressional aide stated that O'Connor's "resignation ought to bring a reexamination of the current restructuring plans to make sure they were not undermining safety."[81]

O'Connor was known to differ with Goldin on safety matters. For example, Goldin complained about excessive reliance on signatures and all the people who signed off before the shuttle flew. O'Connor's view was: "If nobody every signed off on something you wouldn't know what was done." [82] "O'Connor was the heart and soul of this [shuttle]program," one unnamed NASA official said. [83]

CHALLENGER'S ANNIVERSARY

O'Connor's resignation came at a bad time from the standpoint of NASA public relations. This was a time when the 10th anniversary of the Challenger disaster was getting headlines. "Could it Happen Again?" the media asked. The answer was "of course," followed usually by statements about the odds of another disaster. The New York Times said the risk had improved to one in 145 missions thanks to added safety features on the shuttle and overall experience. However, it noted that experts believed declining budgets and demanding schedules were bringing about the same conditions that led to Challenger. It quoted Goldin that "safety is the highest priority" but mentioned others, such as Paul Johnson, the Chairman of the Aerospace Safety Advisory Panel, who spoke of "overzealous reductions" in people and money that enhanced risk.[84]

FROM OVERSIGHT TO INSIGHT

USA executives spent a lot of time reassuring the shuttle workforce that its "bottom line" would be safety, and not profits. The watchword for NASA seemed to be a shift from "oversight" to "insight." The head of USA, Kent Black, said that there was an analogy between the aircraft industry and manned space. "If you think of NASA as the Federal Aviation Administration, think of USA as the operating airline company and the orbiter as a commercial airliner."

In the future, he said, USA "will take on all of the aircraft service and maintenance work, train its flight crews on its own simulators and take on most of the launch and flight control work." At the same time, NASA will "maintain insight into these processes and be the ultimate judge of whether the airline is flying safely, just as FAA does for the airline industry."[85] The problem with this view, critics charged, was that the shuttle was immensely more complex than any airplane and space carried risks that were unique.

On May 31, the White House joined NASA in asking the Aerospace Safety Advisory Panel to review space shuttle safety. Presidential Science Advisor Jack Gibbons said the White House wanted "to ensure that our efforts to improve and streamline the Space Shuttle Program do not inadvertently create unacceptable risk." The report was due in November.[86]

In July, the Safety Panel reported on a field trip to KSC taken in May, prior to the White House directive. The group provided an internal memo to NASA officials. It recommended that NASA slow plans to cut Shuttle Program costs by the end of the decade or risk a serious accident. It said that NASA's attempts to slash shuttle costs by reducing safety inspections and placing day-to-day operations with a private contractor had left the workforce at Kennedy Space Center demoralized and struggling to do its job.

"Overall, it was the clear consensus of the team that a cooling off period is absolutely necessary if KSC operations are to continue safely." Said the internal memo: "NASA and its contractors must step back, permit things to stabilize, and gain some experience with the new operating conditions, before any other major changes are made. This may take a year or more of operations under the United Space Alliance. Without this

hiatus, the safety risk is unacceptable." This risk could "spawn an accident or incident. Given the aging hardware and the need for additional maintenance, many engineers "thought that more rather than fewer inspections were warranted," the memo stated.

"The yellow light which was blinking during our last visit is now burning steadily," the Panel warned. "There was a general consensus that morale is at an all time low. Jobs are being cut, workload and schedule pressure are increasing and skills are eroding."

The report was soon public knowledge. A White House official commented: "The memorandum reflects the concerns that caused us to ask about our own Review." [87] The review for the White House would be presumably more in-depth.

Meanwhile, on October 1, NASA and USA completed contract negotiations and the transition to a private takeover of shuttle operations inexorably moved forward.

CONCLUSION

Discussed has been the subject of privatization and risk. This subject is a dimension of the larger issue of technology management. NASA and its contractors have managed the space shuttle from its initial conceptualization to its present "operational" stage. Each stage has demanded a different management approach. NASA dominated the developmental era and has sought to delegate more and more responsibility to the private sector as the shuttle has matured. Early on, NASA foresaw the prospect for privatization and began planning for the eventual transition in management.

The issue was and is how fast to move from development to operations, from government-run technology to a privately-based system. In theory, the answer depends on "technical" factors, the basic readiness of the technology for routine operations. In reality, pace is influenced also by a variety of organizational imperatives and political forces. It appears that the shuttle became politically ripe for certain

operations (and limited privatization) in the Reagan era, but was not technically ready. Challenger provided the reality-check.

In her book on the Challenger disaster, Dianne Vaughn likens operations to a "culture of production."[88] In a culture that believed the technology was ready for routine flights, in which citizen astronauts could be flown, risk was given less attention than in one that regarded the technology as still developing. Organizational decision-making could be moved to a low level in the production culture. Risks that might otherwise have been seen as "show stoppers" became more "acceptable." Taking risks that went against the grain of specifications in one culture (developmental) could be glossed over in a production or operational culture where the regularity and number of flights were seen as all-important. Vaughn calls this pattern of accepting risks "routinely" as the "normalization of deviance."

The shuttle is generally seen today as at best quasi-operational. Some believe it will never be "routine" because it is so complex and space so forbidding. Yet shuttle flights do take place and the turnaround activities between flights are hardly R&D. Technology does mature. Organizational procedures do become more production-like. There is technological change and learning. There are also organizational and political pressures for NASA to move on, divest itself as much of the day-to-day management of the shuttle as possible, in order to make room for R&D. If there is any consensus at all about NASA, it is that its core mission lies at the frontier of manned spaceflight.

The questions remains -- how fast to go, how far to go in redirecting funds and management attention from shuttle to new enterprises. NASA can delegate a great deal of the shuttle work to the private sector, but there is a limit to replacing "oversight" with "insight." The shuttle remains the world's most sophisticated flying machine that carries human beings. It also remains the enabling technology for most of what NASA wishes to do in manned spaceflight. Finally, the shuttle is a symbol of American technological prowess. Lives are at stake, along with national pride, and NASA's future. The shuttle has moved from the early stages of development, but it is not yet a routine technology. As long as the space shuttle does not perform like an airplane, NASA can

not manage it like the FAA. There is little question that NASA is evolving into a hybrid organization, one that protects its R&D mission, while trying to find a way to give necessary priority to high-risk quasi-operational missions like the shuttle. Where the shuttle is concerned, NASA can delegate work, but not ultimate responsibility.

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