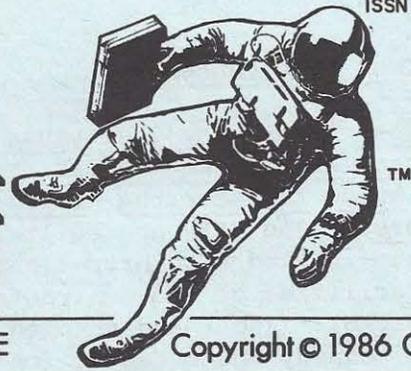


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The Challenger Tragedy: Causes and Consequences

At 11:39 A.M. on January 28, the Space Shuttle Challenger, flying Mission 51-L, was destroyed by an explosion during launch, killing all seven crew members aboard.

Although all details are not yet in, it appears that a joint connecting two segments of the right-hand Shuttle Solid Rocket Booster (SRB) began to leak severely about 59 seconds into the flight, allowing the white-hot gases inside the booster to escape in a huge plume from the side of the SRB. This plume became a miniature rocket of its own, acting as a blowtorch which would melt anything in its path, and producing abnormal stress on the SRB and its attach points. The plume burned, unnoticed by crew, computers or ground personnel, for fully thirteen seconds.

Finally, 72 seconds into the flight, at an altitude of nearly nine miles, the aft attach point on the right-hand SRB came loose due either to stress or to the blowtorch effect. Immediately, the SRB pivoted around its still-connected forward attach point and drove the SRB's nose into the huge, fuel-filled external tank, rupturing it and leaking an explosive mix of hydrogen and oxygen propellants into the air. These propellants then detonated. The explosion, combined with the vehicle's speed of over 1,200 miles per hour, annihilated the external tank and orbiter, killing the crew instantly. The remnants plummeted into the Atlantic Ocean, while the two orphaned SRBs, still flying despite the rupture in one of them, continued upward for a short while until destroyed by range safety officers.

Killed in the Challenger were Mission Commander Francis R. "Dick" Scobee; Mission Pilot Navy Cdr. Michael J. Smith; Mission Specialists Judith A. Resnik, USAF Lt. Col. Ellison S. Onizuka, and Ronald E. McNair; Hughes Payload Specialist Gregory B. Jarvis; and Christa McAuliffe, a Concord, New Hampshire schoolteacher who had won the honor of being the first teacher to go into space.

I felt only sympathy for the lost astronauts' families, the ground personnel at NASA, and the employees of the space agency's contractors. In the days after the disaster, the shock and horror felt by all concerned was only too apparent to those of us who followed the tragedy on television and in print.

However, as the weeks went by, the facts of the matter began to emerge. As they did, the sympathy I felt was supplemented by anger and bitterness as the disaster became less and less a case of the law of averages catching up with the Shuttle (as it must for all forms of transportation) and more and more a case of a long series of avoidable missteps and bad decisions which were, more often than not, made for political rather than engineering reasons.

The causes of the Challenger's destruction, and the resulting consequences for the American space effort, appear to originate from the decisions of a series of bureaucrats and politicians operating within a convoluted web of command involving the upper echelons of government, NASA, and the aerospace industry.

Part One: The Causes

The most likely physical cause of the disaster was the sealing at the joints that hold together the Solid Rocket Boosters. The SRBs are built in large segments, filled with propellant at the Utah facilities of SRB contractor Morton Thiokol, Inc., and shipped by rail to the Kennedy Space Center (one booster is built in four segments since an SRB built as a single unit would be too long to travel by rail). There they are stacked and assembled. The joint between segments relies on an asbestos-filled putty and two elastomer "O"-ring seals to prevent gases from escaping the booster interior (see Fig. 1 at right). Without going into technical details (I recommend to the reader the detailed continuing coverage of the Shuttle investigation in the magazine Aviation Week and Space Technology) it appears that excessive cold --less than 45° F.--can prevent these seals from working properly, which can result in the leak which led to the explosion.

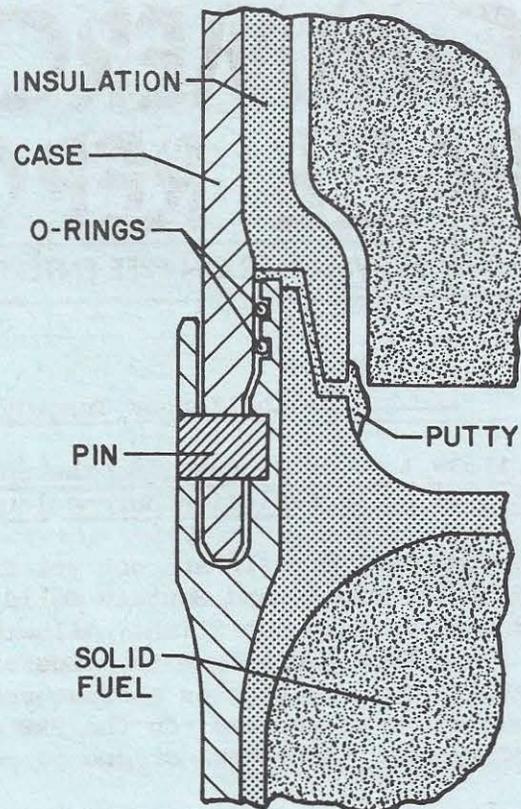


FIG. 1: JOINT DETAIL

Here the bureaucracy begins to rear its ugly head. It was revealed at the hearings of the presidential commission investigating the Challenger disaster that Thiokol and NASA engineers had known since 1982 that seal failure could lead to destruction of the Shuttle, and that the backup seal was in fact unreliable. It was then that the seals were reclassified as a "Criticality One" item, defined as a non-redundant item (not including primary structural elements), the loss of which would lead to the Shuttle's destruction. Such an item requires a special waiver from NASA to be used in the Shuttle system. The primary "O"-ring seal received such a waiver in early 1983. (Just as a side note: there are apparently 829 items in the Shuttle system that have received such waivers--213 on the SRB alone. Think about it.) Since then, NASA and Thiokol have been investigating the seals, and numerous design changes were already under consideration to eliminate the problem. However, they had not yet been implemented.

According to testimony at the hearings, on January 27 (the day before launch) Thiokol engineers, concerned about the seals and the cold weather, urged that Mission 51-L be postponed. Thiokol's representative at Kennedy Space Center, Allan J. McDonald, agreed. However, urged by NASA officials at the Marshall Space Flight Center, McDonald's superiors at Thiokol overruled him, and the official Thiokol statement okayed the launch. The apparent reason: insufficient data indicating that the launch would be unsafe, a startling reversal of the policy of supreme caution which has been characteristic of NASA's public image in the past. Even more startling: this entire debate--on a Criticality One system--took place at a launch decision-making level known as Level 3. According to other testimony from higher NASA officials, word of this controversy never reached as high as Level 2, much less Level 1 or the astronauts themselves. The Challenger flew--and was destroyed.

The hearings continue, and the question of the seals is not yet fully answered. However, in tracking this one item down, the commission is overlooking the larger picture. The Challenger disaster stemmed not just from misguided decisions made the day before the flight, but from misguided decisions made years ago.

As the Shuttle is currently designed, there is no abort mode for the first two minutes of flight while the Solid Rocket Boosters are burning. Should the orbiter attempt to disconnect from the external tank and flee while the SRBs are applying thrust, the orbiter would pivot sharply backwards at its rear connection to the external tank and rip itself apart. And, there is no way that the current SRBs can be shut down once they have been ignited. Ejection seats at the speeds and altitudes of the latter portion of the SRB burn are useless. Two minutes--with the astronauts at the mercy of a system containing 213 Criticality One items.

It is inconceivable that any competent designer of an aerospace flight system would create a vehicle which lacked the capability for safe abort during the most critical part of a launch. Aircraft have designed into them the capability to survive multiple failures during all portions of the flight regime: it is called intact abort. Loss of power to an engine or to one of the hydraulic systems are some of the contingencies the designer must face and deal with to the satisfaction of his company management, the airplane buyer, and the FAA or the USAF. When a mistake is made, such as the infamous DC-10 problem involving the loss of all hydraulic power (due to damage of the leading edge hydraulic lines when the port engine separated from the wing), there is justifiable outrage. Airplane buyers and the traveling public avoid the plane with the problem until that problem is resolved. We do not have that luxury with the Shuttle, largely due to NASA's monopoly status, enforced by the space agency's pressure on competing American launch systems (more on this in Part Two of this article).

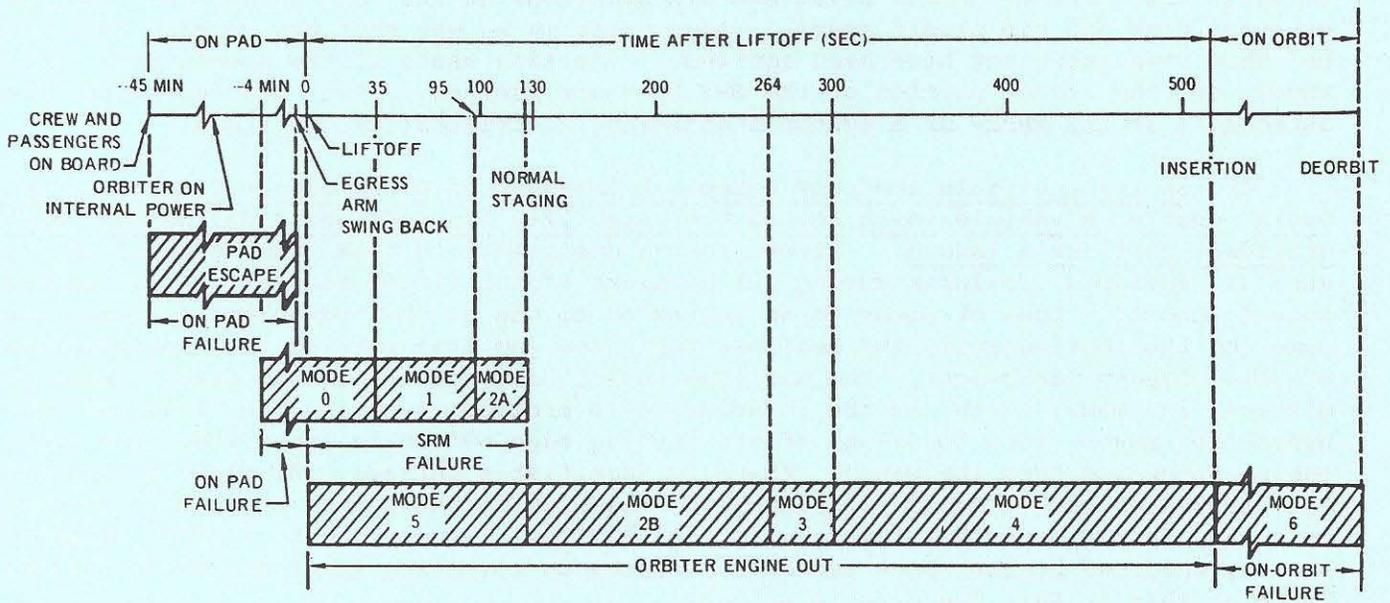
The first decision failure for the government space program was the initial choice of solid rocket boosters for the Shuttle--not so much for the safety issues, but because of the terrible design impacts which helped make the Shuttle a non-starter to begin with. Solids have their place (for example on military weapons which need instant response) but are not, in the opinion of many designers, suited for a reusable role. Difficult to reload and handle, loaded with expensive propellant, difficult to throttle, they force space vehicle designers to extremes which were known to be unnecessary.

The usual argument for the SRBs is that Congress would not appropriate, nor the President ask for, sufficient funds to build a two-staged, fully reusable Shuttle. But before a two-staged design was considered, a stage-and-one-half design called "Starclipper," proposed by Lockheed Missiles and Space Co., was suggested. With an expendable drop tank for the bulk of its liquid oxygen and hydrogen propellants, but no outboard boosters (solid or otherwise), the Starclipper was both technologically feasible and would have been reasonably economical to operate. However, for reasons which are somewhat obscure, the NASA administrator of the time, James Fletcher (who is likely to be NASA administrator again soon) and Shuttle designer Max Faget (now President of Space Industries, Inc.) chose the solid booster route.

Even so, competent designers could still have managed to meet NASA's requirement (at the time of the Phase C/D Shuttle contract award) that the system employ solid-fueled boosters and done so without compromising safety. In the contract proposal made by Aerojet Solid Propulsion Co. in 1973, Aerojet proposed that the Shuttle SRB be manufactured in a single unit, rather than being assembled from segments. To avoid the rail travel problem mentioned earlier, Aerojet would have processed and filled the boosters at a plant in Dade County, Florida, and shipped them to the Kennedy Space Center by barge. In this way, safety would be improved by eliminating the seal problem altogether. However, Aerojet did not get the contract and Thiokol did, even though Thiokol's proposal was ranked last out of four competing bids. Why? Officials involved claimed that Thiokol's bid was lowest. The fact that the chairman of the Senate budget committee in control of NASA's budget was Senator Frank Moss from Utah, or the fact that James Fletcher was an ex-president of the University of Utah and his wife was from Brigham City, Utah (Thiokol's hometown) doubtless had little to do with the decision.

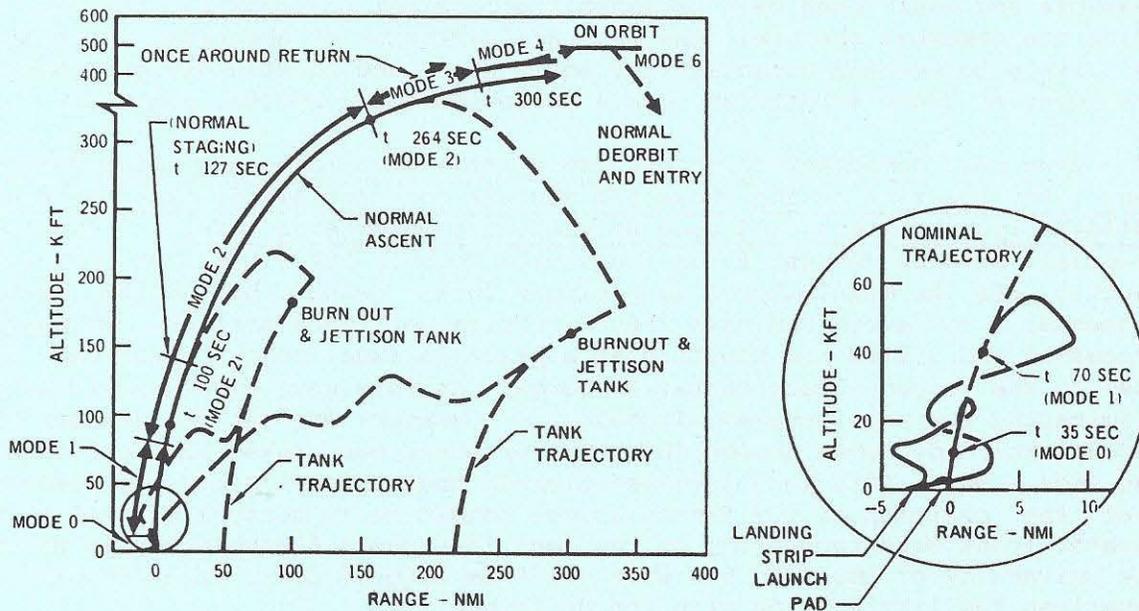
FIG. 2
ABORT CAPABILITY

Easterly Mission



| ABORT MODE | DESCRIPTION | ABORT MODE | DESCRIPTION |
|------------|---|------------|---|
| PAD ESCAPE | EMERGENCY EGRESS TO TOWER PLATFORM AND GROUND SHELTER (2 MINUTES) USING ELEVATOR OR SLIDEWIRES | 2B | SAME AS 2 EXCEPT SRMS HAVE BEEN PREVIOUSLY STAGED. |
| 0 | SHUTDOWN SSME, THRUST NEUTRALIZE SRMS, SEPARATE ORBITER FROM TANK, FIRE ABORT ROCKET, GLIDE TO LANDING. | 3 | USE 109% EPL, BURN OMS ENGINES IN PARALLEL WITH SSME, INSERT INTO ONCE AROUND ORBIT, SEPARATE AND DEORBIT TANK, ENTER AND GLIDE TO LANDING. |
| 1 | SHUTDOWN SSME, THRUST NEUTRALIZE SRMS, JETTISON ABORT ROCKET, SEPARATE ORBITER FROM TANK, GLIDE TO LANDING | 4 | USE 109% EPL, BURN OMS DOWN TO 350 FPS, INSERT INTO 50 x 100 NMI ORBIT, CIRCULARIZE AT 100 x 100 NMI ORBIT, STAY ON ORBIT, NORMAL DEORBIT, ENTRY AND LANDING. |
| 2A | USE 109% EPL, THRUST NEUTRALIZE AND SEPARATE SRMS, MANEUVER TOWARD LANDING SITE, SHUT DOWN SSME, SEPARATE TANK, GLIDE TO LANDING. | 5 | USE 109% EPL, STEER TO SRM BURNOUT, SEPARATE SRMS, CONTINUE IN MODE 2 ABORT. |
| | | 6 | DEORBIT AND RETURN TO LANDING SITE AT FIRST OPPORTUNITY. |

ABORT TRAJECTORIES



Still, seals or no seals, it is possible to go even further to make SRBs safe. This is clearly shown in at least one of the Space Shuttle proposals done at that time: the McDonnell Douglas (MDAC)/TRW Report No. E0600, dated May 12, 1972 (in response to NASA RFP No. 9-BC421-67-40P).

Abort considerations drove the MDAC Shuttle proposal. At every point during the flight, even stationary on the pad, the MDAC Shuttle had abort options for the crew and the orbiter (these options are detailed in Figure 2 at left). This abort capability was possible due primarily to a small solid propellant abort rocket positioned between the three SSME orbiter engines (Figure 3 below).

This clever abort system was dual functional: used in an abort situation to get the orbiter away from the stack, the abort motor was also fired (and then jettisoned) during a normal flight after it was no longer needed for abort purposes. This added about 100 feet per second to the Shuttle's velocity, so the system was not just dead weight.

The Mode 1 abort illustrated in Figure 4 was intended for altitudes between 20,000 and 80,000 ft. Note that the illustration shows a time frame about two seconds before the actual Challenger explosion.

But, you argue, NASA has said that there was no way to determine during the Challenger flight that the right solid booster was failing.

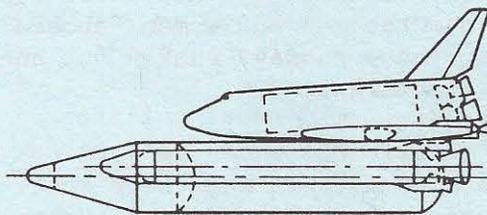
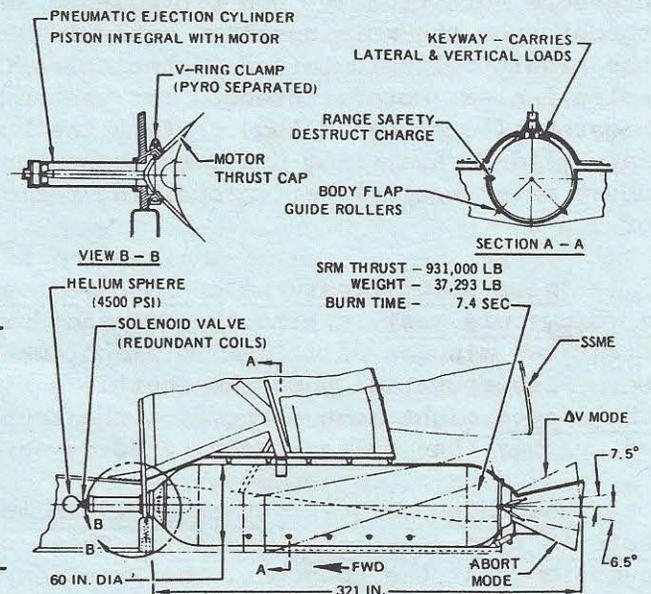


FIG 3: ORBITER ABORT SRM INSTALLATION



As mentioned earlier, no one was aware of danger as the deadly plume burned for at least thirteen seconds before the explosion. So even with an abort rocket, the Challenger and its crew would have been finished.

With the Shuttle NASA built, true. With the one MDAC proposed, no. MDAC engineers knew that a failure of the SRB would be catastrophic. For that reason they studied the possible failures of the SRB. These are listed in the table in Figure 5 (next page) and include ignition problems, case burn-throughs, nozzle burnthroughs (which almost occurred during an early Shuttle mission), premature separation of one or both SRBs, and most ironically, "O"-ring seal leakage.

FIG 4: MODE 1 ABORT TRAJECTORY

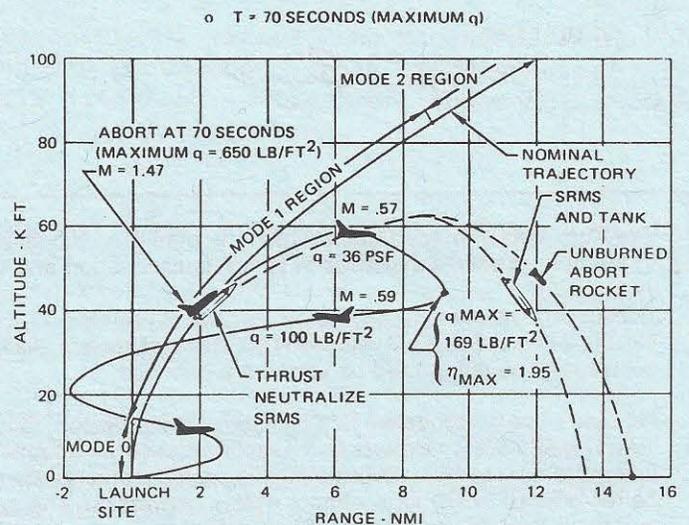


FIG 5: SRM MALFUNCTION DETECTION FOR SAFETY

| FAILURE MODE | CAUSE | DETECTION METHODS | PREVENTIVE MEASURES | CONSEQUENT ACTIONS |
|----------------------|---|---|---|---|
| NO IGNITION | <ul style="list-style-type: none"> LOSS OF IGN. SIGNAL IGNITER MISFIRE | <ul style="list-style-type: none"> CHAMBER PRESSURE NOZZLE EXIT BURN WIRE | <ul style="list-style-type: none"> REDUNDANT IGN. SYSTEMS HOLDDOWN UNTIL THRUST BUILDUP | <ul style="list-style-type: none"> PAD HOLD DOWN |
| CASE BURN THROUGH | <ul style="list-style-type: none"> CRACKED PROP. GRAIN BONDING FAILURE INSULATION DEFECT | <ul style="list-style-type: none"> CHAMBER PRESSURE | <ul style="list-style-type: none"> NDE INSPECTION (X-RAY ULTRASONICS) LIBERAL INSULATION DESIGN MARGINS | <ul style="list-style-type: none"> INITIATE AND ABORT ORBITER |
| NOZZLE BURN THROUGH | <ul style="list-style-type: none"> INSULATION OR BONDING FAILURE | <ul style="list-style-type: none"> GUIDANCE MEASUREMENTS | <ul style="list-style-type: none"> NDE INSPECTION LIBERAL INSULATION DESIGN MARGINS | <ul style="list-style-type: none"> INITIATE TN AND ABORT ORBITER |
| "O" RING LEAKAGE | <ul style="list-style-type: none"> SEAL FAILURE AT SEGMENT OR NOZZLE JOINTS | <ul style="list-style-type: none"> BURN THROUGH WIRE CHAMBER PRESSURE | <ul style="list-style-type: none"> REDUNDANT SEALS LOW PRESSURE LEAK CHECK | <ul style="list-style-type: none"> INITIATE TN AND ABORT ORBITER |
| PREMATURE SEPARATION | <ul style="list-style-type: none"> ATTACH STR. FAILURE PREMATURE SIGNAL | <ul style="list-style-type: none"> BREAK WIRE | <ul style="list-style-type: none"> ADEQUATE DESIGN MARGIN ELECTRICAL INTERLOCKS | <ul style="list-style-type: none"> TN OF REMAINING SRM AND ABORT ORBITER |

MDAC proposed a burn-through wire sensor to determine if the "O"-ring was leaking. If it was, their SRB could be "thrust-neutralized" by firing a pyrotechnic charge which would open a vent at the top of the motors, dropping the chamber pressure drastically and providing a second port for gas to escape to offset the thrust from the main nozzle. This idea was a requirement, successfully tested, for the highly reliable United Technologies/Chemical Systems Division UA 1207 7-segment solid-fueled motor intended for use on the USAF Manned Orbiting Laboratory Titan booster (later cancelled). With the boosters' thrust cancelled, the orbiter can safely drop away from boosters and external tank. If the Shuttle is too low, the abort motor would fire, propelling the orbiter away from danger at an acceleration of 3 g's.

These safety features could have been incorporated into the Shuttle boosters at a minuscule cost. With the SRB shutdown system and the orbiter abort motor, the first two minutes of a Shuttle flight would no longer be deadly. Had these systems been incorporated into the Shuttle's final design, the men and women aboard the Challenger might have emerged on the Kennedy Space Center runway, shaken but unharmed, rather than being precipitated in shreds into the Atlantic.

Why these safety systems were discarded is a question to which we have not been able to find a specific answer. Their weight was minimal, as was their cost. The question that the Congress, the President's commission, and the news media should be asking as they investigate the causes of the Challenger's destruction is not should the launch have taken place, but rather who approved the design which gave the orbiter and the crew no chance at all during the first two minutes of flight?

Next Month: Part Two--The Consequences

Until next time,

Tom Brosz

The Commercial Space Report (C.S.R.) is published monthly, and endeavors to report and analyze developments in the field of private initiatives in space transportation and exploitation.

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