The Columbia Space Shuttle disaster: science and the profit system

Part 1: The physical cause of the accident and the decay of shuttle infrastructure

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19 September 2003

On February 1, 2003, the Space Shuttle Columbia was destroyed upon reentry into the earth's atmosphere, killing all seven crew members. Shortly after the incident, the Columbia Accident Investigation Board (CAIB) was set up to investigate the causes of the disaster. The board summarized its findings in a report released August 26. This series of three articles analyzes the report and the accident itself.

Part 1 discusses the physical cause of the accident—a breach in the orbiter's Thermal Protection System caused by a foam strike during the shuttle's launch. The second part analyzes schedule pressures and the reaction of shuttle engineers and management after the launch. The third and final part looks at the underlying cause of the accident: the subordination of the scientific purposes of the shuttle to a political and economic system dominated by the demands of private profit.

The report is available at the CAIB web site: http://www.caib.us*. All numbers in parentheses refer to page numbers of the report.*

The publication of the findings of the Columbia Accident Investigation Board (CAIB) provides an opportunity to analyze the underlying causes of the *Columbia* Space Shuttle disaster. From the beginning of its investigation, the Board—led by Admiral Harold Gehman and composed primarily of individuals associated in some manner with NASA or the military—indicated that it would not attempt to assign blame for the accident. The conclusions of the report largely whitewash the role of private contractors and politicians in creating the conditions that led to the accident, and the recommendations that the board produced in no way address the fundamental causes of the accident.

Nevertheless, the material gathered in the investigation presents a damning indictment of the process of privatization and budget cutbacks that has characterized NASA operations over the past decade.

The material cause of the accident

According to the investigation board, the preponderance of evidence indicates that the disintegration of the *Columbia* upon reentry was a consequence of damage the shuttle sustained during its launch. Approximately 82 seconds after launch, a large piece of foam insulation from the external fuel tank came loose, striking the protective paneling on a region of the left wing of the orbiter. The paneling—composed of a material known as Reinforced Carbon-Carbon (RCC)—is designed to protect the wing and other sections of the orbiter from the extraordinarily high temperatures generated during reentry.

"During re-entry," the report states, "this breach in the Thermal Protection System allowed superheated air to penetrate the leading-edge insulation and progressively melt the aluminum structure of the left wing, resulting in a weakening of the structure until increasing aerodynamic forces caused loss of control, failure of the wing, and breakup of the Orbiter" (49).

To understand precisely what happened, it is necessary to understand something about the space shuttle and its different components.

Human space flight is a technological achievement of enormous complexity. The space shuttle itself comprises a number of different elements: the orbiter, which holds the astronauts and mission payload; the space shuttle main engines; the external fuel tank; and the solid rocket boosters. According to the report, the shuttle is "assembled from more than 2.5 million parts, 230 miles of wire, 1,060 valves, and 1,440 circuit breakers. Weighing approximately 4.5 million pounds at launch, the Space Shuttle accelerates to an orbital velocity of 17,500 miles per hour—25 times faster than the speed of sound—in just over eight minutes" (14).

The energy required to fuel the main engines of the shuttle is generated by more than 500,000 gallons of oxygen and hydrogen stored at launch in the external tank. To keep them in a liquid state, the gasses must be cooled to extremely low temperatures, and thus the external tank requires a layer of foam that insulates the tank from the relatively high temperatures of the surrounding air. The insulation also helps prevent the formation of ice on the outside of the tank.

A the beginning of launch, the main component of the shuttle thrust is provided by the solid rocket boosters, which burn solid fuel stored separately from the liquid hydrogen and oxygen. At full blast, the two boosters and the engines combined generate some 7.3 million pounds of thrust; that is, they generate a force capable of lifting an object weighing 7.3 million pounds. The two solid rocket boosters separate from the shuttle about two minutes after launch, after which the main engines take over completely.

The energy required to put the shuttle into space must be dissipated upon reentry. Most of it is released in the form of extremely high temperatures generated as the orbiter enters the earth's atmosphere. The nose and leading edge of the wings are exposed to temperatures of up to 3,000 degrees Fahrenheit. Without its Thermal Protection System—and in particular the RCC panels located in the most vulnerable areas—the orbiter would simply burn up, as indeed happens to the external tank when it is jettisoned early in the shuttle flight.

A new external tank is constructed for each flight by Lockheed Martin, which together with Boeing is the major contractor for NASA. The piece of foam that broke away during the launch of the Columbia was covering a complex-shaped structure on the tank called the bipod, which forms part of the connection between the tank and the orbiter.

In considering the immediate physical cause of the accident, a number of questions arise. Why did the foam detach from the external tank? Was this a product of avoidable structural defects? Given the critical role of the RCC paneling, could it have been better protected from a potential foam strike?

The investigation found that because of the complex shape of the bipod area, the foam in that region must be applied by hand, and this process can introduce pockets of air and debris. "NASA personnel believe that testing conducted during [CAIB's] investigation, including the dissection of as-built hardware and testing of simulated defects, showed conclusively that preexisting defects in the foam were a major factor, and in briefings to the Board, these were cited as a necessary condition for foam loss." (52).

One way in which such defects could have contributed to the foam loss is by a process known as "Cryopumping," whereby air that has entered cracks in the foam is liquefied upon coming into contact with the tank itself. As temperatures increase after launch, the liquid may evaporate and expand, increasing pressure within the foam. Combined with the vibrations and stress placed on the tank during launch, the defects were sufficient to cause the foam to fall from the tank.

The design of the external tank is 30 years old and out of date. The design of the bipod in particular is not optimal, causing difficulties in the application of the foam. The board found: "The External Tank and the bipod ramp were not tested in the complex flight environment, nor were fully instrumented External Tanks ever launched to gather data for verifying analytical tools. The accuracy of the analytical tools used to simulate the External Tank and bipod ramp were verified only by using flight and test data from other Space Shuttle regions." (52).

The RCC panels struck by the foam age over time and must be replaced periodically. The most important cause of panel aging is oxidation, a chemical process that results when oxygen penetrates the coating on the panels. The oxidation reaction reduces the panel's mass, making it more vulnerable to debris impact.

However, oxidation cannot be directly measured, so it is estimated analytically and the panels are replaced periodically according to this estimate. Many of the panels had not reached their limit and were therefore original equipment—that is, they have been used on every mission of the *Columbia* since it was built. Panel 8, which is the panel that the board believes was damaged by the foam, has one of the shorter life spans—just over 60 missions—and had never been replaced.

The estimates of the life of the panel did not take into account the increased oxidation that occurred as a result of the penetration of the RCC panels by zinc oxide. In 1992, small pinholes were first discovered in the RCC panels of the *Columbia*. "There is no zinc in the leading edge support system, but the launch pad corrosion protection system uses an inorganic zinc primer under a coat of paint, and this coat of paint is not always refurbished after a launch" (57). Past texts have shown that rain washed the primer off the launch pad onto the RCC panels of the orbiter. This may have contributed to the oxidation of the panels and weakened them, making them more susceptible when struck by the foam.

It had been widely stated by NASA managers that foam impact on an RCC panel could not have damaged the panel sufficiently to cause the burn-through. To disprove this assumption, the board conducted impact tests that demonstrated the contrary, tests that NASA and its contractor never carried out. The RCC panels are also manufactured by Lockheed.

Infrastructural decay

The report states that negligence on the part of NASA and its contractors did not contribute to the foam defects; however, the evidence presented by the board itself contradicts this. Why has the design of the external tank not been updated, and why have measures not been put in place to improve the quality of the foam? This question is particularly significant given that the *Columbia* flight was not the first instance of the kind. The report states that there is evidence of foam loss on more than 80 percent of the 79 missions for which imagery is available. The specific region involved in the *Columbia* accident—the left bipod ramp—shed foam on an estimated 10 percent of previous flights.

"Over the life of the Space Shuttle Program, Orbiters have returned with an average of 143 divots in the upper and lower surfaces of the Thermal Protection System tiles, with 31 divots averaging over an inch in one dimension." (122).

The Space Shuttle *Atlantis* had been struck by foam coming off a different region in 1988. One of the thermal tiles was knocked off, an event that could have been catastrophic. When that hit was discovered shortly after launch, the crew of the orbiter was directed to inspect the craft, something that did not happen with the *Columbia*.

One of the most serious instances of left bipod foam shedding occurred just two flights before STS-107, the last *Columbia* flight. However, the incident was not classified as serious. Instead, flight managers—including former Shuttle Program Manager Ron Dittemore and STS-107 Mission Manager Linda Ham—accepted a faulty rationale that stated that foam loss was safe, a decision that was inconsistent with previous classifications of foam loss.

In diminishing the significance of the foam loss, NASA management resorted to outright falsification. The NASA Headquarters Safety Office issued a report that massaged data to produce a 99 percent probability that foam would not be shed from the same area on future flights. "This calculation was a sleight-of-hand effort to make the probability of bipod foam loss appear low rather than a serious grappling with the probability of bipod ramp foam separating" (126).

The main reason for downplaying the safety risk from foam shedding appears to have been pressure on NASA to keep a strict launch schedule, pressure that originated from the Bush administration. NASA management wanted to avoid delays that might have arisen if the problem had to be corrected before the next flight. This is discussed in more detail in the second part of this series.

The specific incidents that led to the accident are only part of the general decay in space shuttle infrastructure over the past several years. The decay has been bound up with the dwindling budget made available to the shuttle program and the process of privatization that has placed decisions on safety and infrastructure upkeep in the hands of private corporations—particularly Boeing and Lockheed Martin. The joint venture of these two companies—known as United Space Alliance—controls the dominant part of the shuttle program's contracts.

The RCC panels and foam defects were not the only evidence of decay in the shuttle's infrastructure that was discovered by the board. Also on the external tank are the bolt catchers, which are designed to catch the bolts that are ejected when the external tank separates from the orbiter after launch. If the bolts are not caught, they may strike and damage the orbiter. The board found that the catchers did not meet specifications: "Every bolt catcher tested failed well below the expected load range of 68,000 pounds. In one test, a bolt catcher failed at 44,000 pounds, which was two percent below the 46,000 pounds generated by a fired separation bolt" (87).

The contractor responsible for the catchers—United Space Alliance—did not properly perform the mandatory inspection of the catchers.

In addition: "Board investigators have identified deteriorating infrastructure associated with the launch pads, Vehicle Assembly Building, and the crawler transporter... For example, NASA has installed nets, and even an entire sub-roof inside the Vehicle Assemble Building to prevent concrete from the building's ceiling from hitting the Orbiter and Shuttle stack...

"In 2000, NASA identified 100 infrastructure items that demanded immediate attention. NASA briefed the Space Flight Advisory Committee on this 'Infrastructure Revitalization' initiative in November of that year. The Committee concluded that 'deteriorating infrastructure is a serious, major problem,' and, upon touring several Kennedy Space Center facilities, declared them 'in deplorable condition'" (114-5). NASA's budget proposal to improve infrastructure was denied by Congress.