# “TRAGEDY AND STANDARDS DEVELOPMENT”

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The Space Shuttle has been described by some as the most complicated machine ever built by mankind. Designed as a reusable space transport system, the Space Shuttle utilizes a thermal protection system to shield the vehicle and crew from the intense heat experienced by the shuttle when re-entering Earth's atmosphere. The thermal protection system was developed out of the experience of the Mercury, Gemini, and Apollo programs, as well as testing with the U.S. Air Force's X-15 rocket plane. For twenty-seven missions the thermal protection system protected the Space Shuttle Columbia. On February 1st, 2003, the Columbia's twenty-eighth mission, the thermal protection system failed. The shuttle broke up in the lower atmosphere, sixteen minutes before she was to land, killing all seven members of her crew. The engineering standard for the thermal protection system, a standard developed by The National Aeronautics and Space Administration (NASA), was performance based and stated that the system would be re-usable for 100 missions. It was not a fault with the standard, though, that caused the loss of the Columbia. A standard is only as good as the organization that utilizes it, and in the case of NASA, the organization did not possess the culture of safety necessary for the thermal protection system standard to fulfill its purpose in protecting the shuttle.

The Space Shuttle is what aeronautical engineers call a lifting body. After re-entering the atmosphere, the Space Shuttle glides to her landing. The concept of a spacecraft based on a re-entry lifting body is decades old. The development of such a vehicle and how to shield it from the heat of re-entry was not without controversy.

> During the original studies of lifting-reentry vehicles during the late 1950s and 1960s, there had been a great debate over the relative merits of active cooling systems versus passive systems for the vehicle structure. The active systems were attractive—on paper—but nobody could quite figure out how to make them work.[1]

The original space capsules that carried Alan Shepard and John Glenn into space were not reusable. They instead utilized what is called ablative shielding. The Mercury, Gemini, and Apollo space capsules "were protected during re-entry by shedding layers of a heavy, resinous heat shield through a process called ablation.[2]" The only experience NASA or the U.S. Air Force had with a reusable spacecraft came from the experiments with the X-15 rocket plane. The X-15 utilized a hot-structure approach, which "required the use of rare and expensive superalloys, and there was always a great deal of doubt whether it would have worked on a vehicle as large as the Shuttle.[3]" At the Lockheed Missiles and Space

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[1] Jenkins, Dennis R. "The Shuttle's Thermal Protection System (TPS)." 7 July 2006. http://history.nasa.gov/sts1/pages/tps.html

[2] "Orbiter Thermal Protection System." KSC Release No. 11-89 February 1989. 8 June 2006. http://www-pao.ksc.nasa.gov/nasafact/tps.htm

[3] Jenkins, Dennis R. "The Shuttle's Thermal Protection System (TPS)." 7 July 2006. http://history.nasa.gov/sts1/pages/tps.html

Company, another concept involving re-usable surface insulation was being developed, "and by December 1960, Lockheed had applied for a patent for a reusable insulation material made of ceramic fibers.[4]" There was interest from NASA to use this technology in the Apollo program, and

> Lockheed developed a 32-inch-diameter radome for the Apollo spacecraft; it was made from a filament-wound shell and a lightweight layer of internal insulation cast from short silica fibers. But the Apollo design changed, and the radome never flew.[5]

This experience was still very valuable to Lockheed and led to the development of a fibrous mat called Lockheat.[6] The Lockheat material

> was impregnated with organic fillers such as methyl methacylate (Plexiglas) to achieve a structural quality. These composites were not ablative—they did not char to provide protection. Instead Lockheat evaporated, producing an outward flow of cool gas.

The development of Lockheat continued, and "[b]y 1965, this had led to the development of LI-1500, the first of what became the Shuttle tiles.[7]" Lockheed continued to develop the LI-1500 concept, and as a subcontractor to Rockwell, Lockheed "would produce the material in two different densities to protect

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[4] Jenkins, Dennis R. "The Shuttle's Thermal Protection System (TPS)." 7 July 2006. http://history.nasa.gov/sts1/pages/tps.html
[5] Ibid.
[6] Ibid.
[7] Ibid.

different heating regimes—9 pounds per cubic foot (designated LI-900) and 22 pounds per cubic foot (LI-2200).[8]" These would be placed on the shuttle as tiles to provide shielding for a variety of different components.

As research continued and technology was developed, a standard to which a future thermal protection system began to evolve at NASA.

> NASA and Rockwell originally believed that the leeward side (top) of the vehicle would not require any thermal protection. But in March 1975, the Air Force Flight Dynamics Laboratory conducted a briefing for Space Shuttle engineers on the classified results of the ASSET, PRIME, and boost-glide reentry vehicle (BGRV) programs that indicated that leeward-side heating was a serious consideration. The thermal environment was not particularly severe, but it easily exceeded the 350 °F capability of the aluminum skin.[9]

As new design requirements became apparent, it was evident that the Lockheed tiles would not be applicable to every component of the shuttle, and that new types of tiles would need to be developed to meet these new requirements.

After decades of research and years of development, these requirements were consolidated into a performance-based standard for a thermal protection

[8] Jenkins, Dennis R. "The Shuttle's Thermal Protection System (TPS)." 7 July 2006. http://history.nasa.gov/sts1/pages/tps.html
[9] Ibid.

system for the Space Shuttle. The thermal protection system will shield the shuttle's outer skin from temperatures above 350 degrees F and be re-usable for 100 missions. The materials are to operate in a temperature range from -250 degrees F in orbit to nearly 3000 degrees F during re-entry.[10] Certain components are required to withstand greater temperatures than others. The shuttle has "approximately 24,300 tiles and 2,300 Flexible Insulation Blankets on the outside of each orbiter.[11]" On the shuttle, "[t]he orbiter's nose cone, including the chin panel, and the leading edge of its wings are the hottest areas during re-entry.[12]" Maximum heating occurs about twenty minutes before touch-down, and the thermal protection system must protect these components from temperatures as high as 3,000 degrees F.[13] The materials used to protect these components are "Reinforced Carbon-Carbon (RCC)...a light gray, all-carbon composite.[14]" For other elements of the shuttle exposed to temperatures less severe than that of the nose cone, a different material is used.

> Coated black tiles-known as High-Temperature Reusable Surface Insulation (HRSI)-cover the lower surface of the orbiter, areas around the

[10] "NSTS 1988 News Reference Manual." September 1988. 11 July 2006. http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/sts_sys.html#sts-tps

[11] "Orbiter Thermal Protection System." KSC Release No. 11-89 February 1989. 8 June 2006. http://www-pao.ksc.nasa.gov/nasafact/tps.htm

[12] Ibid.

[13] Ibid.

[14] Ibid.

> forward windows, upper body flap, the base heat shield, the "eyeballs" on the front of the Orbital Maneuvering System (OMS) pods, and the leading and trailing edges of the vertical stabilizer and the rudder speed brake. The black tiles are located where temperatures can reach as high as 2,300 degrees F.[15]

For components that have lower temperature requirements, "[a]bout 70 percent of an orbiter's external surface is shielded from heat by a network of more than 24,000 tiles formed from a silica fiber compound.[16]" In many cases, more advanced materials such as Flexible Insulation Blankets have replaced tiles on some of the upper surfaces of the orbiter.[17] For these components of the shuttle,

> Coated white tiles-known as Low-Temperature Reusable Surface Insulation (LRSI)-are designed to insulate the spacecraft from temperatures up to 1,200 degrees F. LRSI tiles were originally used extensively, but are now replaced in most areas by Flexible Insulation Blankets. LRSI is still used on the upper surface of the forward fuselage above the crew windows and on some parts of the OMS pods.[18]

The standard for the thermal protection system, then, was that the shuttle's outer skin was protected above 350 degrees F. The materials on the nose, chin, and

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[15] "Orbiter Thermal Protection System." KSC Release No. 11-89February 1989. 8 June 2006. http://www-pao.ksc.nasa.gov/nasafact/tps.htm
[16] Ibid.
[17] Ibid.
[18] Ibid.

leading edges of the wings of the spacecraft must be capable of operating in temperatures as low as -250 degrees F to temperatures approaching 3,000 degrees F. The materials on the upper forward fuselage of the spacecraft must operate in temperatures as low as -250 degrees F to temperatures approaching 2,300 degrees F. The materials on areas of the forward, mid, and aft fuselage must operate in temperatures as low as -250 F to temperatures approaching 1,200 degrees F. Where tiles are not employed,

> [w]hite blankets made of coated Nomex felt reusable surface insulation are used on the upper payload bay doors, portions of the midfuselage and aft fuselage sides, portions of the upper wing surface and a portion of the OMS/RCS pods. The FRSI blankets protect areas where temperatures are below 700 F.[19]

This is the standard that NASA developed, in conjunction with Rockwell, Lockheed, and the U.S. Air Force, for thermal protection systems on production Space Shuttles.

The temperature requirements for each tile and blanket of the shuttle were developed and tested to support the performance requirement that the thermal protection system be re-usable for 100 missions. On February 1st, 2003, the Space Shuttle Columbia re-entered the atmosphere to conclude a mission in which her

[19] "NSTS 1988 News Reference Manual." September 1988. 11 July 2006. http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/sts_sys.html#sts-tps

crew traveled more than six million miles in 16 days.[20] Designated STS-107, Columbia's mission was the Space Shuttle Program's 113th flight and Columbia's 28th.[21] The flight had been flawless, with one exception:

> [a]t 81.7 seconds after launch, when the Shuttle was at about 65,600 feet and traveling at Mach 2.46 (1,650 mph), a large piece of hand-crafted insulating foam came off an area where the Orbiter attaches to the External Tank. At 81.9 seconds, it struck the leading edge of Columbia's left wing. This event was not detected by the crew on board or seen by ground support teams until the next day, during detailed reviews of all launch camera photography and videos. This foam strike had no apparent effect on the daily conduct of the 16-day mission, which met all its objectives.[22]

The breach occurred in the thermal protection system on the leading edge of the left wing, in the vicinity of the lower half of Reinforced Carbon- Carbon panel number 8.[23] This breach allowed "superheated air to penetrate through 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

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[20] "Columbia Accident Investigation Board: Board Statement." Spaceflight Now. 29 July 2006. http://spaceflightnow.com/columbia/report/006boardstatement.html
[21] "Columbia Accident Investigation Board: Synopsis." Spaceflight Now. 29 July 2006. http://spaceflightnow.com/columbia/report/011synopsis.html
[22] Ibid.
[23] "Columbia Accident Investigation Board: Board Statement." Spaceflight Now. 29 July 2006. http://spaceflightnow.com/columbia/report/006boardstatement.html

caused loss of control, failure of the wing, and break- up of the Orbiter.[24]" The question that logically follows is, was a fault in the thermal protection system standard the result of the destruction of the Space Shuttle Columbia and the death of her crew, or was is a cultural and organizational failure that led to the failure of the thermal protection system and subsequently the loss of the Columbia?

The Columbia Accident Investigation Board (CAIB) determined that the answer lied in the latter part of the question. The standard for the thermal protection system was developed out of three decades of testing and research. The standard never stated that the system was to survive an impact, nor was the fuselage of the shuttle designed to withstand a breech in the thermal protection system. The Board found that the breach occurred because

> [c]ultural traits and organizational practices detrimental to safety were allowed to develop, including: reliance on past success as a substitute for sound engineering practices (such as testing to understand why systems were not performing in accordance with requirements); organizational barriers that prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements; and the evolution of an informal chain of

[24] "Columbia Accident Investigation Board: Board Statement." Spaceflight Now. 29 July 2006. http://spaceflightnow.com/columbia/report/006boardstatement.html

> command and decision-making processes that operated outside the organization's rules.[25]

The board also went on to say that

> [t]he organizational causes of this accident are rooted in the Space Shuttle Program's history and culture, including the original compromises that were required to gain approval for the Shuttle, subsequent years of resource constraints, fluctuating priorities, schedule pressures, mischaracterization of the Shuttle as operational rather than developmental, and lack of an agreed national vision for human space flight.[26]

In the wake of the Apollo program, NASA found itself with a budget that was not commensurate with its ambitions. By 1970, the White House had lost its appetite for large space programs, and NASA was forced to seek allies to justify developing a shuttle that had been part of a vision involving multiple space stations and re-usable space planes.[27] NASA turned to the Department of Defense for support. Among other requirements, the Department of Defense mandated that the shuttle be capable of delivering classified payloads up to 60 feet in length and weigh up to 18,200 kilograms, and take off and return to a West Coast launch site after a single

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[25] "Columbia Accident Investigation Board: Board Statement." Spaceflight Now. 29 July 2006. http://spaceflightnow.com/columbia/report/006boardstatement.html
[26] Ibid.
[27] Berger, Brian. "Last Chapter Opens For Space Shuttle Born Of Compromise," Space News: Business Report. 7 July, 2005. 29 July, 2006. http://www.space.com/spacenews/businessmonday_050815.html

polar orbit. This required increasing the shuttle's dimensions and weight, as well as adding delta-shaped wings and a more robust thermal protection system.[28] All these specifications increased costs, and in 1971, the White House Office of Management and Budget granted NASA only five of the $10 Billion it requested for the shuttle.[29] NASA developed a shuttle design that fit within the $5 billion ceiling for development, but it would prove far more costly to operate and entail greater risks than initially forecast. This included external solid-fuel boosters and an external fuel tank,[30] neither of which were accounted for in Lockheed's development of the thermal protection system. John Logsdon, director of the Space Policy Institute at George Washington University and a member of the Columbia Accident Investigation Board believes that the "White House made a policy mistake in 1972 by 'putting NASA in a position where it had to promise more than it could achieve' in order to sell the space shuttle program and ensure a post-Apollo future for human space flight.[31]"

The cultural and organizational changes in NASA from the Apollo program to the Space Shuttle program can be traced back to NASA leadership in the early 1970s.

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[28] Berger, Brian. "Last Chapter Opens For Space Shuttle Born Of Compromise," Space News: Business Report. 7 July, 2005. 29 July, 2006. http://www.space.com/spacenews/businessmonday_050815.html
[29] Ibid.
[30] Ibid.
[31] Ibid.

> James Fletcher became the next NASA Administrator in 1971 and he immediately pared down the space shuttle transportation system to its present day form. After canceling the space stations, the further Moon exploration, and the flight to Mars by 1986, the Nixon Administration started the United States on a road away from Space and James Fletcher seemed to be the Drum Major for the parade. After trying to get Europe and Canada interested in the space shuttle Fletcher showed he had no real political skill as Webb had during his years of accomplishing the Apollo Program. Fletcher went along with the Congressional and bureaucratic feeding frenzy on the various NASA projects while problems with the space shuttle mounted.[32]

A culture of compromise evolved at NASA in safety and mission assurance. Perhaps the most indicting finding by the CAIB was that

> There are conflicting roles, responsibilities, and guidance in the Space Shuttle safety programs. The Safety & Mission Assurance Pre-Launch Assessment Review process is not recognized by the Space Shuttle Program as a requirement that must be followed (NSTS 22778). Failure to consistently apply the Pre-Launch Assessment Review as a requirements

[32] Graham, John F. "Chapter 21: Space Organizations." 1995. 29 July, 2006. http://www.space.edu/projects/book/chapter21.html

document creates confusion about roles and responsibilities in the NASA safety organization.[33]

NASA officials did not see fit to use the same pre-launch safety standards that apply to robots for a vehicle carrying seven human beings.

These indictments of the culture at NASA have led to a number of reforms. Chief among them is the creation of an "independent Engineering and Safety Center (NESC) at the agency's Langley Research Center in Hampton, Va., to provide comprehensive examination of all NASA programs and projects.[34]" After two catastrophic Space Shuttle accidents in seventeen years, NASA is looking to reform a culture that has sacrificed operational and safety standards. In the case of the thermal protection system, three decades of development and testing produced a system that protected the shuttles for 113 missions. Of all recommendations made by the CAIB for the thermal protection system, only two dealt with the system itself, and both recommendations involved improvements to withstand impacts from minor debris and to enhance the ability to re-enter the atmosphere with minor structural and sub-structural damage to the leading edges of the

[33] "Columbia Accident Investigation Board: Findings." Spaceflight Now. 29 July 2006. http://spaceflightnow.com/columbia/report/allfindings.html

[34] "NASA Announces Independent Engineering And Safety Center." Press Release 03-239. 15 July, 2003. 31 July 2006. http://www.nasa.gov/home/hqnews/2003/jul/HQ_03239_safety_center.html

shuttle.[35] All other recommendations dealt with the development of inspection procedures and modeling capabilities to better understand the tiles and the impact of debris on the integrity of the thermal protection system.[36]

The CAIB found no fault with the standard for the thermal protection system in that the standard developed was appropriate and the improvements recommended were from a disaster that could not have been anticipated forty years ago when the system was devised. Rather compromises in the safety standards, as well as compromises in the final design of the shuttle led to the Columbia disaster. An engineering standard is only as good as the organization that utilizes it. For the United States and her incredibly robust legal system, the Columbia accident speaks volumes about standards and liability. For corporations adhering to voluntary standards, they must be cognizant of the vigilance needed in maintaining those standards. NASA is the example of the consequences paid by seven human beings for a lack of vigilance in the maintenance of standards over a period of decades. NASA developed the standard for the systems it would operate. Rockwell and Lockheed manufactured components to that standard, but the compromises in the final design and the operation of the shuttle made those standards insufficient to guarantee the survival of equipment and crew.

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[35] "Columbia Accident Investigation Board: Recommendations." Spaceflight Now. 29 July 2006.
http://spaceflightnow.com/columbia/report/225recommendations.html

[36] Ibid.

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Tragedies Facts. 41. Drinking the Kool-Aid. In 1978, over 900 members of the Peopleâ€™s Temple Agricultural Project, led by Jim Jones, died in what is now called the Jonestown massacre. These deaths were the result of murder-suicide committed by drinking powdered soft-drink mix combined with cyanide and prescription sedatives. Tragically, many of the groupâ€™s members, including at least 89 infants and elderly people, consumed the poisonous mixture. While many regard the Jonestown deaths as mass suicide, most people donâ€™t know that the survivors revealed a dark truth: those that drank the poison a The tragedy of the commons is a problem in economics that occurs when individuals neglect the well-being of society in the pursuit of personal gain. This leads to over-consumption and ultimately depletion of the common resource, to everybody's detriment. For a tragedy of the commons to occur a resource must be scarce, rivalrous in consumption, and non-excludable. Solutions to the tragedy of the commons include the imposition of private property rights, government regulation, or the development of a collective action arrangement. 1:26. Tragedy of the Commons. Understanding the Tragedy of t Tragedy (from the Greek: Ï„ÏÎ±Î³á¿³Î´Î¯Î±, tragÅidia) is a form of drama based on human suffering and, mainly, the terrible or sorrowful events that befall a main character. Traditionally, the intention of tragedy is to invoke an accompanying catharsis, or a "pain [that] awakens pleasure", for the audience. While many cultures have developed forms that provoke this paradoxical response, the term tragedy often refers to a specific tradition of drama that has played a unique and important role historically in