Loss of Signal *Aeromedical Lessons Learned from the STS-107 Columbia Space Shuttle Mishap*

Robert Patlach, Wyle, Houston, TX , Philip C. Stepaniak, MD, and Helen W. Lane, PhD, NASA Johnson Space Center, Houston, TX

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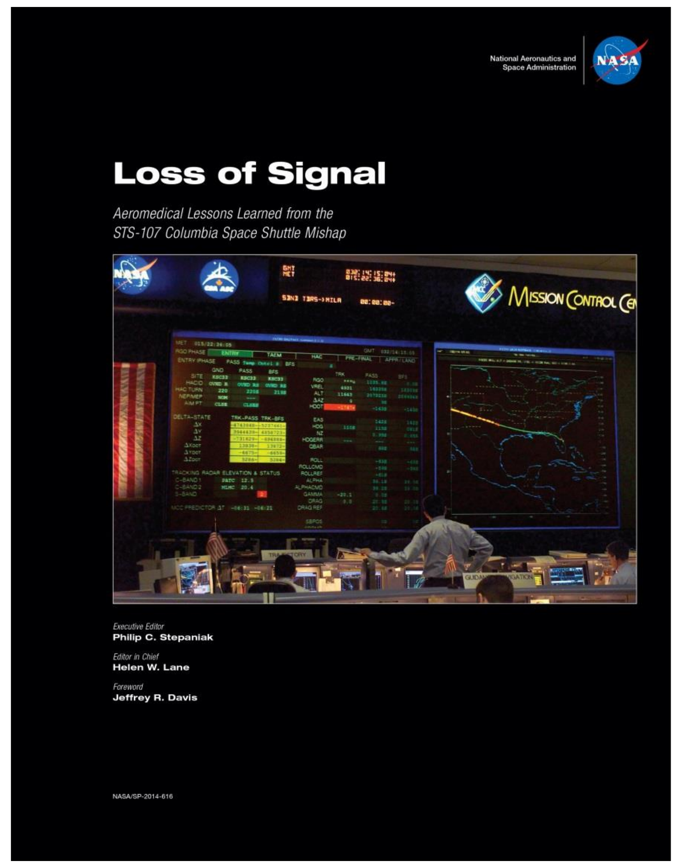


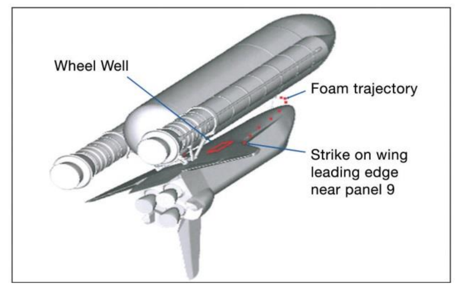
Loss of Signal *Aeromedical Lessons Learned from the STS-107 Columbia Space Shuttle Mishap* is available in print from the US Government Bookstore, http://bookstore.gpo.gov/, or as a free download at the JSC Technical Report Server: http://ston.jsc.nasa.gov/collections/TRS/

Loss of Signal, a NASA publication to be available in May 2014, presents the aeromedical lessons learned from the Columbia accident that will enhance crew safety and survival on human space flight missions. These lessons were presented to limited audiences at three separate Aerospace Medical Association (AsMA) conferences: in 2004 in Anchorage, Alaska, on the causes of the accident; in 2005 in Kansas City, Missouri, on the response, recovery, and identification aspects of the investigation; and in 2011, again in Anchorage, Alaska, on future implications for human space flight. As we embark on the development of new spacefaring vehicles through both government and commercial efforts, the NASA Johnson Space Center Human Health and Performance Directorate is continuing to make this information available to a wider audience engaged in the design and development of future space vehicles. **Loss of Signal** summarizes and consolidates the aeromedical impacts of the Columbia mishap process—the response, recovery, identification, investigative studies, medical and legal forensic analysis, and future preparation that are needed to respond to spacecraft mishaps. The goals of this book are to provide an account of the aeromedical aspects of the Columbia accident and the investigation that followed, and to encourage aerospace medical specialists to continue to capture information, learn from it, and improve procedures and spacecraft designs for the safety of future crews.

The Mission, Crew and Mishap

SPACEHAB Research Double Module

STS-107 Insignia



The foam strike on the leading edge of the wing at 81.9 seconds after lift-off.

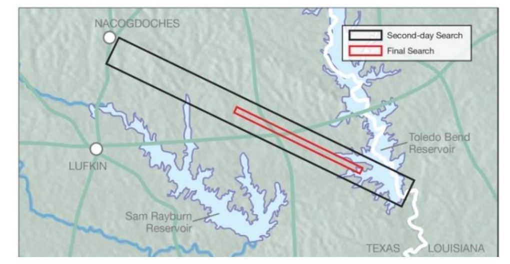
When STS-107's flight was announced, the Space Shuttle Program was focused on assembling the International Space Station. However, NASA decided to have this one last research-dedicated Space Shuttle mission using the SPACEHAB laboratory. STS-107 research focused on the consequences of microgravity on physical and living systems. The underlying goals were to enhance the well-being of people on earth using microgravity for basic scientific understanding with the expectation that this knowledge might enable scientists to build better spacecraft and to understand the human system. Once the science was selected, NASA mission managers and the STS-107 crew worked with the investigators to ensure the highest quality of research.

Columbia launched the morning of January 16, 2003 for the 16-day mission. During ascent, foam debris from the external tank shed during the extreme conditions of launch and struck the left wing of Columbia exactly 81.9 seconds into the flight. When it was recognized that Columbia had suffered a debris strike, analysis and engineering experts worked to identify the significance of this event for vehicle integrity. Because operational experience with previous foam debris strike events had shown that such strikes had never caused significant structural damage, this event was not considered mission critical and the flight continued uninterrupted.

On the morning of February 1st, Columbia began her return to Earth. At 08:59:32 CST, no further telemetry was received form Columbia. This moment would come to be known as the **Loss of Signal**.

The Response

Barksdale AFB, home of the Eighth Air Force, was the strategic site for the Columbia Mishap Investigation Team



Second Day search area (60 mi x 5 mi) and final search area (25 mi x 1 mi)

Honor Guard Protocol for Columbia Crewmembers at Barksdale AFB

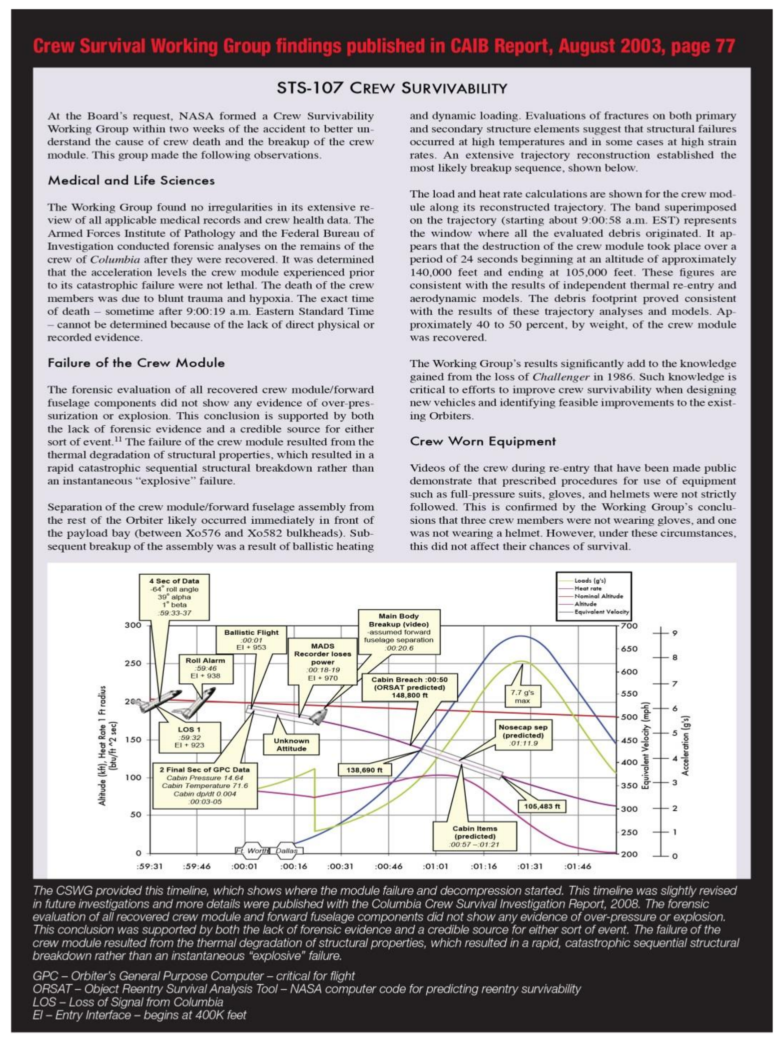
Within hours of the mishap, the Columbia Mishap Investigation Team (MIT) was activated, and by 3:30 PM CST members of the Johnson Space Center and Kennedy Space Center teams were enroute to Barksdale Air Force Base (AFB), LA, the strategic command center for recovery operations. The primary objective of the MIT medical team was to receive, analyze, identify and transport human remains to the Armed Forces Institute of Pathology (AFIP) at Dover AFB, DE. Additionally, a team from the Office of the Armed Forces Medical Examiner deployed to Barksdale AFB to begin preliminary examination of recovered remains.

A disaster field office was established in Lufkin, Texas, to manage the crewmember recovery effort carried out by 2000 personnel. Search methods for the crew included line searches, dog and horse teams, and aerial spotters. As remains were discovered, they were photographed and catalogued by Federal Bureau of Investigation (FBI) Evidence Response Teams (ERT). Human remains were transported from the recovery point to Lufkin, TX, then to Barksdale AFB and subsequently flown to Dover AFB.

The initial search area for crewmembers was 200 miles long and 50 miles wide. As recovery patterns emerged, the search area was redefined as a more manageable 60 mile x 5 mile corridor. The final area was 25 miles x 1 mile.

The first crewmember remains were transported from Lufkin, TX, to Barksdale AFB on February 2, 2003. Twelve days after the accident, all crewmembers had been identified. The official search for remains was terminated on February 13th.

The Investigation


Crew Survival Working Group findings published in CAIB Report, August 2003, page 77

STS-107 CREW SURVIVABILITY

At the Board's request, NASA formed a Crew Survivability Working Group within two weeks of the accident to better understand the cause of crew death and the breakup of the crew module. This group made the following observations.

Medical and Life Sciences

The Working Group found no irregularities in its extensive review of all applicable medical records and crew health data. The Armed Forces Institute of Pathology and the Federal Bureau of Investigation conducted forensic analyses on the remains of the crew of *Columbia* after they were recovered. It was determined that the acceleration levels the crew module experienced prior to its catastrophic failure were not lethal. The death of the crew members was due to blunt trauma and hypoxia. The exact time of death – sometime after 9:00:19 a.m. Eastern Standard Time – cannot be determined because of the lack of direct physical or recorded evidence.

Failure of the Crew Module

The forensic evaluation of all recovered crew module/forward fuselage components did not show any evidence of over-pressurization or explosion. This conclusion is supported by both the lack of forensic evidence and a credible source for either sort of event.[11] The failure of the crew module resulted from the thermal degradation of structural properties, which resulted in a rapid catastrophic sequential structural breakdown rather than an instantaneous "explosive" failure.

Separation of the crew module/forward fuselage assembly from the rest of the Orbiter likely occurred immediately in front of the payload bay (between Xo576 and Xo582 bulkheads). Subsequent breakup of the assembly was a result of ballistic heating and dynamic loading. Evaluations of fractures on both primary and secondary structure elements suggest that structural failures occurred at high temperatures and in some cases at high strain rates. An extensive trajectory reconstruction established the most likely breakup sequence, shown below.

The load and heat rate calculations are shown for the crew module along its reconstructed trajectory. The band superimposed on the trajectory (starting about 9:00:58 a.m. EST) represents the window where all the evaluated debris originated. It appears that the destruction of the crew module took place over a period of 24 seconds beginning at an altitude of approximately 140,000 feet and ending at 105,000 feet. These figures are consistent with the results of independent thermal re-entry and aerodynamic models. The debris footprint proved consistent with the results of these trajectory analyses and models. Approximately 40 to 50 percent, by weight, of the crew module was recovered.

The Working Group's results significantly add to the knowledge gained from the loss of *Challenger* in 1986. Such knowledge is critical to efforts to improve crew survivability when designing new vehicles and identifying feasible improvements to the existing Orbiters.

Crew Worn Equipment

Videos of the crew during re-entry that have been made public demonstrate that prescribed procedures for use of equipment such as full-pressure suits, gloves, and helmets were not strictly followed. This is confirmed by the Working Group's conclusions that three crew members were not wearing gloves, and one was not wearing a helmet. However, under these circumstances, this did not affect their chances of survival.

The CSWG provided this timeline, which shows where the module failure and decompression started. This timeline was slightly revised in future investigations and more details were published with the Columbia Crew Survival Investigation Report, 2008. The forensic evaluation of all recovered crew module and forward fuselage components did not show any evidence of over-pressure or explosion. This conclusion was supported by both the lack of forensic evidence and a credible source for either sort of event. The failure of the crew module resulted from the thermal degradation of structural properties, which resulted in a rapid, catastrophic sequential structural breakdown rather than an instantaneous "explosive" failure.

GPC – Orbiter's General Purpose Computer – critical for flight
ORSAT – Object Reentry Survival Analysis Tool – NASA computer code for predicting reentry survivability
LOS – Loss of Signal from Columbia
EI – Entry Interface – begins at 400K feet

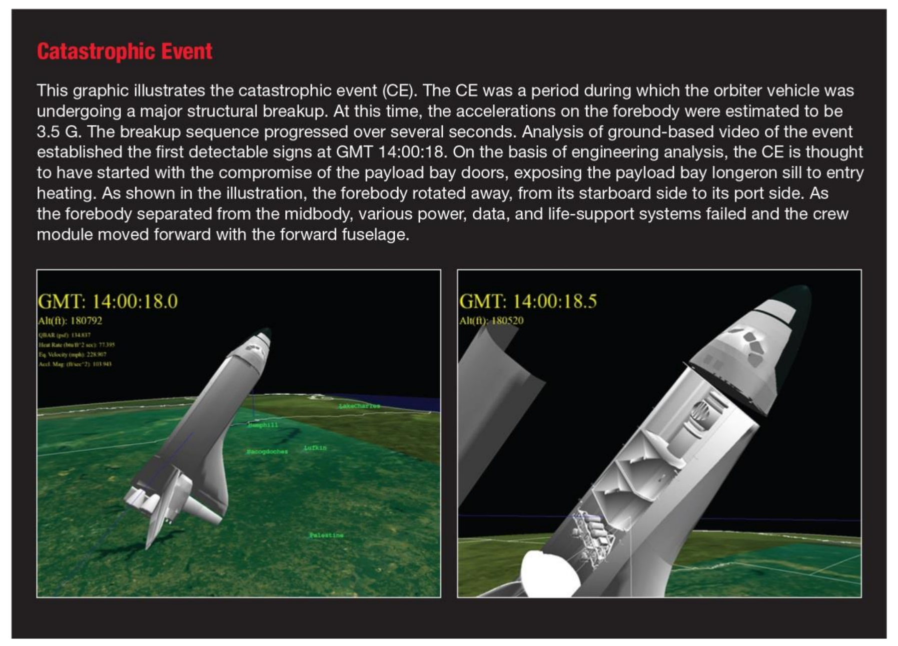
The Crew Survival Working Group - Ninety minutes after loss of signal, Admiral Harold W. Gheman, Jr., was named Chair of the Columbia Accident Investigation Board (CAIB) by the NASA Administrator. Once formed, the CAIB appointed advisors to the chair to assist in the focus and management of the investigations. These advisors included a chief flight surgeon (CFS) and medical consultant, James Bagian, M.D., a former astronaut and lead medical investigator for the Challenger accident that occurred in January 1986. The CAIB requested the formation of the Crew Survival Working Group (CSWG), chaired by Dr. Bagian, to determine the cause of death of the crew and determine the "survival gap" (what equipment or procedures might have kept the crew alive). The CSWG report was included as Appendix G.12 of the final CAIB report in October 2003.

The Columbia Crew Survival Investigation Report released in 2008 captured the lessons learned from the loss of Columbia and its crew and documented recommendations for improving crew survival for future human spaceflight vehicles. The report identified the five potentially lethal events the crew experienced and addressed whether current technology existed that could have precluded the lethality of the event. The five potential lethal events were:

1. Cabin depressurization
2. Exposure to a dynamic rotating environment with non-conformal helmets and a lack of upper body restraint
3. Separation from the crew module and seats with associated forces, material interactions and thermal consequences
4. Exposure to near vacuum, aerodynamic accelerations and cold temperatures
5. Ground impact

The Analysis

Columbia's reentry on February 1st initiated a sequence of events which resulted in loss of vehicle control at GMT 13:59:37. The orbiter was rotating, pitching and rolling with a strong and consistent yaw component of the overall motion, but its "belly" was predominantly oriented to the velocity vector. The left wing shed debris for a period of time and then departed the vehicle followed by the catastrophic event (CE): separation of the orbiter forebody from the midbody. The crew module depressurized rapidly. The crew module catastrophic event (CMCE) involved the complete breakup of the crew module.



The forensic medical findings of injuries incurred during and after the CE and the CMCE can be categorized as follows:

1. Mechanical injuries incurred during the CE
2. Depressurization injuries incurred after the CE
3. Mechanical injuries incurred after the CE and before the CMCE
4. Thermal injuries incurred after the CMCE and exposure to the atmospheric environment
5. Common injuries incurred during the CMCE and ground impact

Analysis of legal issues encountered during the recovery and investigation also resulted in valuable lessons learned for future spacecraft aircraft investigations.

The Future

One of the lessons learned from the loss of the Space Shuttle Columbia was that root-cause investigations do not dig deep enough to trace the individual crewmember experiences to determine the successes and failures of protective measures. Past mishap investigations focused on determining the root cause of the mishap and preventing recurrence. However, if the crewmembers were not identified in the causal chain of events, their experiences were not analyzed and lessons were lost.

The crew survival in-depth investigation process supplements the root-cause investigation. The crew survival investigation focus is different from that of the usual mishap investigation. Specifically, the crew survival investigation team investigates the performance of the crew, crew protective equipment, crew-vehicle interfaces, emergency and crew survival systems, training, and procedures that are intended to protect the crew. A crew survival specialist, with extensive mishap investigation and human factors training, leads the team. Typical team members are a medical doctor, a pathologist, a legal representative, and specialists in structures, environmental control and life support systems, flight performance, and crew equipment (crew survival and emergency equipment and crew suits).

The outcomes of the crew survival investigation are the awareness of factors and events that affected crew survivability and recommendations for improving crew survival for future human space flight.