Executive Summary

During the Soyuz 11 mission in 1971 and the STS-107 Columbia mission in 2003, both crews were subjected to violent decompressions which resulted in their deaths. Each incident was caused by different factors, but in both cases the crew would have survived the decompression event if they had been properly wearing their Launch, Entry, & Abort (LEA) suits. The Soyuz 11 crew were not wearing LEA suits at all, and the Columbia crew were likely not wearing their gloves or had their helmet visors lifted. NASA Standard 3001 outlines program requirements with regards to LEA suits. The suits must be easily accessible by the crew, available for quick donning/doffing, and able to accommodate any activity the crew is required to perform.

Relevant Standards

NASA-STD-3001 Volume 1, Rev B
[V1 3004] In-Mission Medical Care
[V1 5002] Astronaut Training

NASA-STD-3001 Volume 2, Rev C
[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure
[V2 6007] Rate of Pressure Change
[V2 9053] Protective Equipment
[V2 9055] Protective Equipment Automation
[V2 11024] Ability to Work in Suits
[V2 11032] LEA Suited Decompression Sickness Prevention Capability

Testing of Orion docking hatch while wearing LEA suit (2019)

Entry Events

Soyuz 11 – June 30, 1971

During separation of the orbital and service modules from the descent module, the pyrotechnic system did not operate as intended. All of the pyrotechnics fired simultaneously rather than the designed sequential firing mode, which was believed to be due to the excessive vibration loads on the vehicle. <u>This caused a pressure equalization seal to open in the descent module at a higher-than-designed altitude, resulting in the rapid depressurization of the crew module.</u> The rapid depress led to loss of consciousness of the crew despite attempts by one of the crew to block the leakage of air from the vehicle. The spacecraft otherwise made a nominal automatic touchdown with no known anomalies at the time of the recovery team.

The lives of Georgi Dobrovolski, Vladislav Volkov, and Viktor Patsayev were lost due to the vacuum experienced. The cause of death for the cosmonauts was hemorrhaging of the blood vessels in the brain, with lesser amounts of bleeding under their skin, in the inner ear, and in the nasal cavity, all of which occurred as exposure to a vacuum environment which caused the oxygen and nitrogen in their bloodstreams to bubble and rupture vessels.

Contributing factors:

- Crew were not wearing pressurized suits for re-entry
- Absence of an open-valve warning system
- The valve was located under a seat and could not be reached and closed in time to prevent decompression
- Absence of an emergency valve-choking system
- No structural shock testing performed for a worst-case scenario

Soyuz 11 Landing Site

Entry Events

STS-107 Columbia – February 1, 2003

Damage to the Thermal Protection System from a debris strike on ascent resulted in the loss of crew and vehicle on entry.
At 81.7 seconds Mission Elapsed Time, a piece of foam insulation from the External Tank (ET) left bipod ramp separated from the ET and struck the orbiter left wing leading edge in the vicinity of the lower half of reinforced carbon-carbon (RCC) panel #8, causing a breach in the RCC. During re-entry, this breach allowed super-heated air to penetrate through the leading edge insulation and progressively melt the aluminum structure of the left wing, resulting in break-up of the orbiter.

This breakup occurred in a flight regime in which, given the design of the orbiter, there was no possibility for the crew to survive. David Brown, Laurel Clark, Michael Anderson, Ilan Ramon, Rick Husband, Kalpana Chawla, and William McCool lost their lives.

STS-107 Columbia Investigation

Contributing factors:

- Depressurization of the crew module, which started at or shortly after orbiter breakup. Existing crew equipment protects for this type of lethal event, but inadequate time existed to configure the equipment for the environment encountered. Forensic investigations showed that while the crew were wearing their LEA suits, several crewmembers were not wearing their gloves, and others had their visors raised at the time of the accident. The crew would have only had about 40 seconds to don gloves and helmets.
- The combination of the lack of upper body restraint and a helmet that, by design, does not internally conform to the head while exposed to cyclical motion resulted in lethal mechanical injuries for some of the unconscious or deceased crew members. If the harnesses had been locked or the crew had been conscious and able to brace, the injuries likely would not have been lethal.
- Separation from the crew module and the seats with associated forces, material interactions, and thermal consequences. Seat restraints played a role in the lethality of this event. Although the seat restraints played a significant role in the lethal-level mechanical injuries, there is currently no full range of equipment to protect for this event.
- Exposure to near vacuum, aerodynamic accelerations, and cold temperatures. Current crew survival equipment is not certified to protect the crew above 100,000 feet.

Overview of LEA Suits

Launch, Entry, and Abort (LEA) suits are worn by crew during active phases of the mission, rather than typical intra-vehicular activities (IVA) or extra-vehicular activities (EVA). They are designed to pressurize in the event of a cabin depressurization, remain buoyant during a water landing*, and assist in crew survival following an emergency or off-nominal escape**.

Below is a comparison of NASA's Advanced Crew Escape Suit (ACES), used at the time of the Columbia disaster, and Roscosmos's Sokol suit, introduced after Soyuz 11 and still in use today.

ACES
3.5 psi nominal pressure
Designed to provide sufficient time of useful consciousness to escape vehicle (not decompression sickness mitigation).

Sokol
5.8 psi nominal pressure
Used following Soyuz 11 disaster where crew succumbed to decompression symptoms.

*NASA realized the importance of buoyancy after a Mercury test mission when Gus Grissom's suit took on water upon landing in the ocean and he nearly drowned.
**The crew of Voskhod 2 landed in remote Siberian wilderness and made use of their emergency supplies to survive relatively unscathed.

See Mishaps During Entry, Descent and Landing OCHMO Technical Brief

LEA Suits – Decompression Sickness (DCS) Mitigation

Overview of DCS

DCS is the result of nitrogen bubbles (emboli) causing damage to tissue. When atmospheric pressure drops, existing nitrogen bubbles in the blood expand, which can be fatal if they make their way to the brain. DCS is split into two categories: **Type I** (characterized by joint pain, single extremity tingling or numbness, and mild skin symptoms), and **Type II** (characterized by potentially fatal central nervous system or cardiovascular symptoms ranging from muscle weakness, confusion, impaired balance, to stroke).

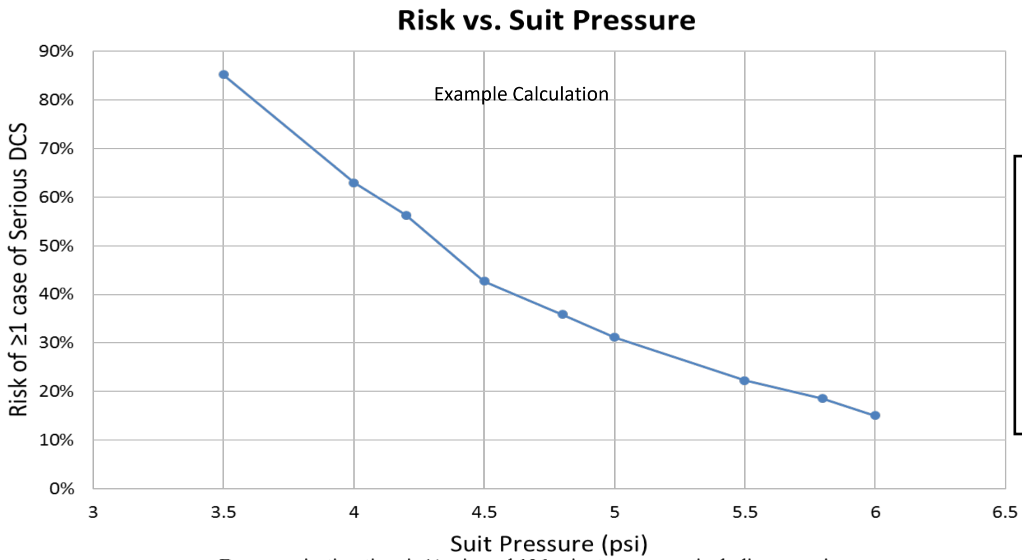
See Decompression Sickness OCHMO Technical Brief

LEA Suit Pressure Mitigates DCS Onset and Symptoms

If the vehicle experiences a rapid loss of pressure, the crew risks suffering from DCS. Their pressurized LEA suits can help mitigate the effects of DCS.

> NASA-STD-3001 Volume 2 Rev C [V2 11032] states "LEA spacesuits shall be capable of a minimum of 40 kPa (5.8 psia) operating pressure to protect against Type II decompression sickness in the event of a cabin depressurization."

Generally, the higher the LEA suit pressure, the lower the risk of Type II DCS. At an LEA suit pressure of 5.8 psi, there is less than a 20% chance of a serious DCS case.



Depressurization time is ½ min and 136 minute exposure including exercise.
Cumulative Binomial Distribution: P(r≥1|n=4, p=serious DCS)

Based on Bubble Dynamic Models for the predication of DCS. See Conkin Et al, Evidence Report:
Risk of Decompression Sickness (DCS), Human Research Program, 2016

Application Notes

- Crew should always wear LEA suits during takeoff and reentry and be ready to pressurize. The crews of both Soyuz 11 and Columbia would have had a better chance of surviving their decompression events if they had been wearing their LEAs. NASA-STD-3001 Volume 2 Rev C [V2 11001] states that "The system shall accommodate efficient and effective donning and doffing of spacesuits for both nominal and contingency operations."
- For a time after Soyuz 11, Soyuz missions moved to two member crews, which allowed enough space for both crewmembers to wear their LEA suits. Later, LEA suits were redesigned to be smaller, which allowed for a three-person crew again. Special consideration should be taken to ensure that the crew can perform all needed tasks while wearing their LEA suits.
- Any valve that vents air out of the vehicle should have automatic fail-safes as well as manual shutoffs. After Soyuz 11, manual ventilation valve handles were added to the spacecraft. Adequate stress testing of critical components must be undertaken to ensure those components operate correctly, even during off-nominal circumstances.

See Chapter 11 and Appendix E of NASA-STD-3001 Volume 2 for relevant standards associated with LEA suits.

Soyuz 11 Crew

STS-107 Columbia Crew

Back-Up

Major Changes Between Revisions

Original → Rev A

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev B and Volume 2 Rev C.

Referenced Standards

NASA-STD-3001 Volume 1 Revision B

[V1 3004] In-Mission Medical Care All programs shall provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence-based PRA, clinical practice guidelines and expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses should consider the needs and limitations of each specific DRM and vehicles. The term "in-mission" covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. In-mission capabilities (including hardware and software), resources (including consumables), and training to enable in-mission medical care, are to include, but are not limited to: (see NASA-STD-3001, Volume 1 Rev B for full standard).

[V1 5002] Astronaut Training Beginning with the astronaut candidate year, general medical training, including first aid, cardiopulmonary resuscitation (CPR), altitude physiological training, carbon dioxide exposure training, familiarization with medical issues, procedures of space flight, psychological training, and supervised physical conditioning training shall be provided to the astronaut corps.

NASA-STD-3001 Volume 2 Revision C

[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure The system shall maintain the pressure to which the crew is exposed to between 26.2 kPa < pressure ≤ 103 kPa (3.8 psia < pressure ≤ 14.9 psia) for indefinite human exposure without measurable impairments to health or performance.

[V2 6007] Rate of Pressure Change For pressure changes >1.0 psi, the rate of change of total internal vehicle pressure shall not exceed 13.5 psi/min.

[V2 9053] Protective Equipment Protective equipment shall be provided to protect the crew from expected hazards.

[V2 9055] Protective Equipment Automation Automation of protective equipment shall be provided when the crew cannot perform assigned tasks.

[V2 11024] Ability to Work in Suits Suits shall provide mobility, dexterity, and tactility to enable the crewmember to accomplish suited tasks within acceptable physical workload and fatigue limits while minimizing the risk of injury.

[V2 11032] LEA Suited Decompression Sickness Prevention Capability LEA spacesuits shall be capable of operating at sufficient pressure to protect against Type II decompression sickness in the event of a cabin depressurization.

Reference List

1. Columbia Crew Survival Investigation Report. *NASA/SP-2008-565*. https://www.nasa.gov/pdf/298870main_SP-2008-565.pdf
2. NASA System Failure Case Studies. *Descent into the Void*. September 2010, Volume 4, Issue 9. https://sma.nasa.gov/SignificantIncidents/assets/descent-into-the-void.pdf
3. Evidence report: Risk of Decompression Sickness (DCS). (2016). Human Research Program – Human Health Countermeasures Element. *NASA*. https://humanresearchroadmap.nasa.gov/evidence/reports/DCS.pdf
4. NASA OCHMO Decompression Sickness (DCS) Risk Mitigation Technical Brief. https://www.nasa.gov/offices/ochmo/human_spaceflight/mishaps-technical-briefs
5. NASA OCHMO Mishaps During Entry, Descent and Landing Technical Brief. https://www.nasa.gov/offices/ochmo/human_spaceflight/mishaps-technical-briefs