In-Space Rescue

Dr. Grant R. Cates
Space Architecture Department

June 26, 2023

This work was sponsored by the Space Safety Institute: https://aerospace.org/ssi

Approved for public release. OTR 2023-00892.

In-Space Rescue Overview

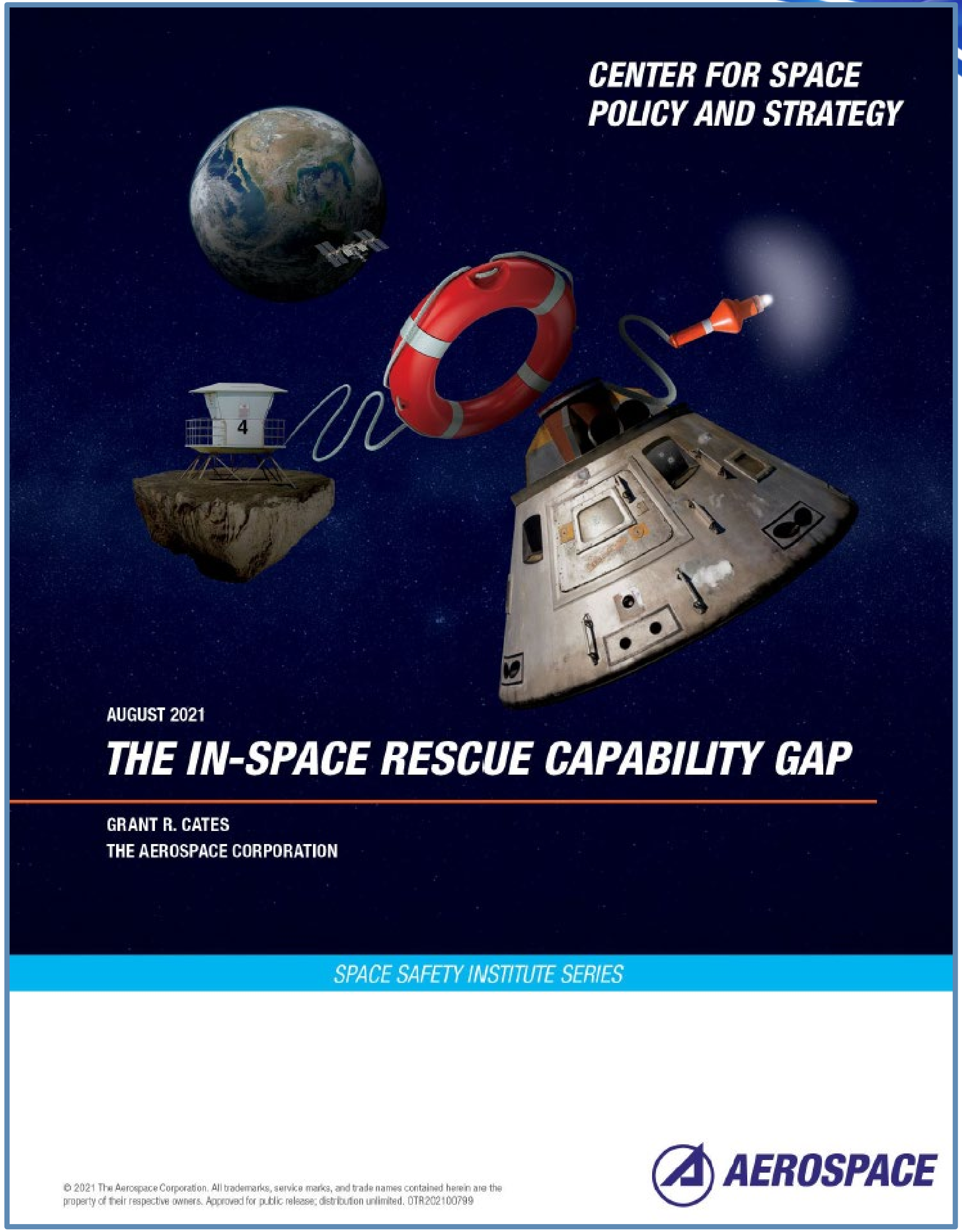
Introduction and Contents Overview

- The In-Space Rescue Capability Gap Paper
- Maritime Explorers
  - *They typically sailed with multiple ships*
  - *Comparison to lunar missions:*
    - Apollo 8 versus Apollo 13
    - Constellation versus Artemis
- Submarine Rescue
- Space Rescue Concepts
- The Outer Space Treaty of 1967
- Space Flight Emergencies Survey by Congress in 1967
- Apollo – Soyuz
- Skylab
- Space Shuttle Mission Requirements
- Loss of Columbia
- Post Columbia
- International Docking System Standard
- Legislative Authorities
- Implications of Space Rescue
- Policy Considerations
- Existing Capabilities
- Conditions for Space Rescue
- Space Rescue Scenarios
- Recommendations

Space rescue has a significant history and instructional analogs, but relatively little to show for it in terms of policies or real capabilities today.

The In-Space Rescue Capability Gap

- Sponsored by Aerospace Corporation's:
  - *Center for Space Policy & Strategy*
  - *Space Safety Institute*
- Published in 2021 by
  - Aerospace
    - https://csps.aerospace.org/papers/space-rescue-capability-gap
  - The Journal of Space Safety Engineering
    - https://www.sciencedirect.com/science/article/pii/S2468896721000665
- Led to several articles, and resulted in collaboration with Jan Osburg at RAND and a panel session at the ASCEND 2022 conference
- Referenced in Aerospace's 2022 Space Safety Compendium
  - *https://aerospace.org/paper/2022-space-safety-compendium*



Maritime Explorers

Maritime Explorers

- With no hope of being rescued at sea, and the potential that ships might become damaged or sink during long journeys, the 10 famous explorers*shown at right set out with multiple ships.
- Single ship expeditions such as John Cabot (1497) and James Cook (1768) were exceptions.
  - *Endeavor ran aground on June 11, 1770 on the great barrier reef.*
  - *The crew managed to detach and beach the ship on June 18 in the mouth of what is now the Endeavour river.*
  - *Seven weeks to repair.*
  - *Set sail again on August 22, 1770.*

- Vasco De Gama – **4 ships** sailed from Lisbon on July 8, 1497: Sao Gabriel, Sao Rafael, Berrio, and unnamed storeship
- John Cabot – **1 ship** sailed May of 1497;
  - ***5 ships** sailed from Bristol in May of 1498 (lost at sea or returned in 1500? Historians are not sure.)*
- Christopher Columbus: **3 ships (**Nina, Pinta, and Santa Maria) sailed in August of 1492
  - ***17 ships** sailed in September of 1493*
  - ***6 ships** sailed in May of 1498*
- Francis Drake – **5 ships** set sail on December 13, 1577: Pelican, Elizabeth, Marigold, Swan, Christopher
- John Smith – **3 ships**: Discovery, Susan Constant, Godspeed
- Ferdinand Magellan – **5 ships**: Trinidad, San Antonio, Victoria, Conception, Santiago
- George Vancouver – **2 ships** sailed from England on April 1, 1791: HMS Discovery and HMS Chatham
- Amerigo Vespucci – **4 ships** sailed May of 1499; **3 ships** sailed May of 1501
- Jeanne Baret – member of Louis Antoine de Bougainville's expedition – sailed with **2 ships** La Boudeuse and Etoile
- James Cook – **1 ship** (HMS Endeavour) sailed on August 26,1768;
  - ***2 ships** (HMS Resolution and HMS Adventure) sailed in 1771)*
  - ***2 ships** (HMS Resolution and HMS Discovery) sailed in 1776*

***** https://didyouknowboats.com/greatest-maritime-explorers-in-history/***

Apollo 8

The only single-ship mission to venture beyond LEO

- Apollo 8 was originally to have been a systems checkout flight in earth orbit for the Apollo command and service module (CSM).
- In August of 1968 the CIA told NASA that the Soviets were planning a crewed lunar orbit mission by year end.
- NASA accelerated the Apollo 8 mission and changed it to a lunar orbit moon mission. The lunar lander was not available yet, so there was no chance of a lunar landing.
- In a declassified October 1968 report, CIA Deputy Director for Science and Technology Carl Ducket referred to the Apollo-8's mission as being "a result of the direct intelligence support that FMSAC [Foreign Missile and Space Analysis Center] has provided to NASA on present and future Soviet plans in space."
- The decision to switch Apollo 8 to a lunar mission was "one of the most risky decisions in the history of spaceflight" according to Fordham University historian Asif Siddiqi.
- The risk was deemed acceptable, given NASA's confidence in the flight hardware, the crew, and the overarching imperative to beat the Russians to the moon.
- The firing of the engine to leave lunar orbit and return to earth was a critical part of the Apollo 8 mission, and all subsequent Apollo lunar missions, and likely all future lunar missions as well.
- Prior to the launch a NASA official was overheard saying, "Just how do we tell Susan Borman, 'Frank is stranded in orbit around the moon'?"

References: Dwayne A. Day, "Spooky Apollo: Apollo 8 and the CIA," *The Space Review*, December 3, 2018 (https://www.thespacereview.com/article/3617/1);
Joel Achenbach, "Apollo 8: NASA's first moonshot was a bold and terrifying improvisation," *Washington Post*, December 21, 2018 (https://www.washingtonpost.com/history/2018/12/20/apollo-nasas-first-moonshot-was-bold-terrifying-improvisation/);

Marooned in Lunar Orbit (1968) by David S. F. Portree

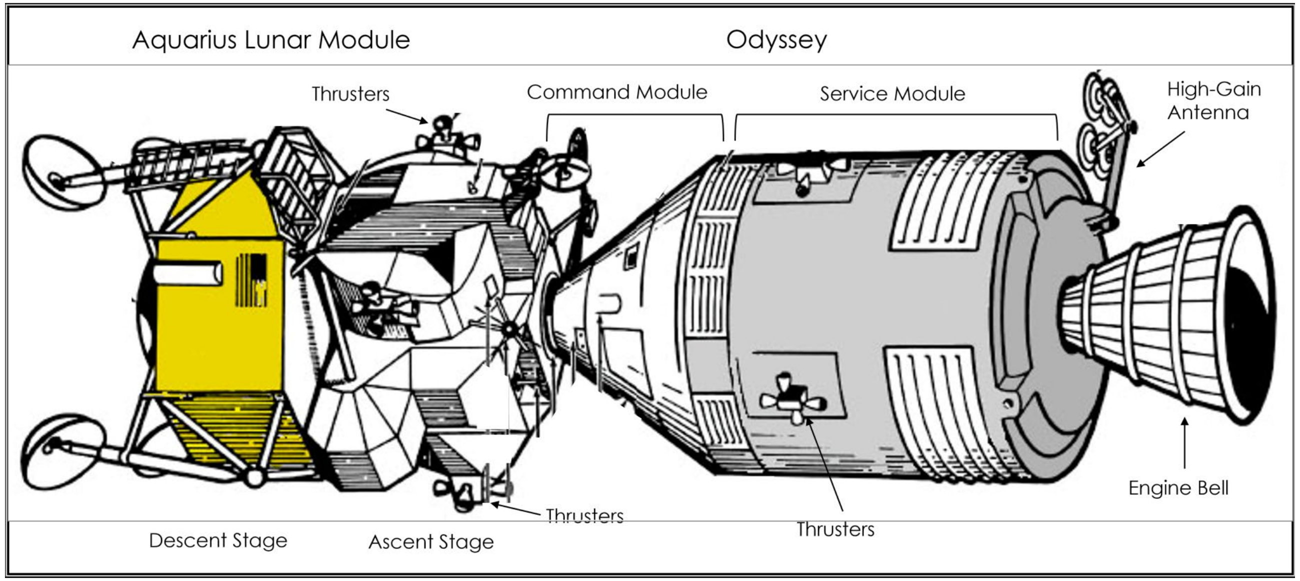
Apollo 8 What-If Scenario

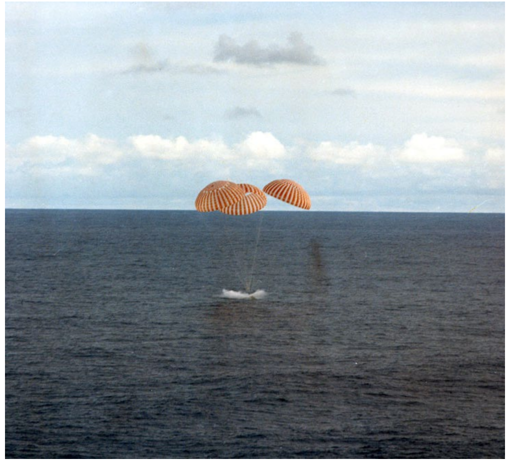
- The Apollo 8 mission to orbit the moon on Christmas Eve 1968 decisively demonstrated U.S. superiority in the Moon Race, but it was also one of the riskiest missions NASA ever flew.
- A. Haron and R. Raymond, engineers with Bellcomm, NASA's Washington, DC-based planning contractor, completed a brief study of what might have happened had the Apollo Command & Service Module's Service Propulsion System's main engine not ignited for the trans-earth-insertion (TEI) burn.
- Specifically, they looked at how long a crew might survive in lunar orbit following a TEI failure.
- If a stranded Apollo CSM crew began to ration its LiOH canisters immediately after TEI failure, they would be able to stretch their survival time to 148 hours.
- In that case, the Apollo 8 crew would have survived until New Year's Eve - the day Haron and Raymond completed their study.
- The Bellcomm study was mainly of academic interest, since a crew stranded in orbit around the moon, 238,000 miles from Earth, could not have been rescued even if they did survive for two or three weeks.
- NASA did not have the ability to maintain a rescue Saturn V rocket and CSM on standby.

https://www.wired.com/2012/05/marooned-in-lunar-orbit-1968/

Lunar Explorers

Apollo - 13





- All Apollo missions to the moon, except of Apollo 8, departed earth with two spaceships: the Command & Service Module, and the Lunar Module.
- Apollo 13 demonstrated the lifesaving quality of having two separate ships that could sustain a crew.

Image Credits: NASA (see https://moon.nasa.gov/resources/399/apollo-13-presentation/)

Hinting at Space Salvage

Grumman's Mock Invoice

GRUMMAN AEROSPACE CORPORATION

BETHPAGE, NEW YORK 11714

ADDRESS REPLY TO:

GRUMMAN AEROSPACE CORPORATION
JOHN F. KENNEDY SPACE CENTER
KENNEDY SPACE CENTER
FLORIDA [illegible]

CABLE ADDRESS
GRUMAIR

17 April 1970

Mr. T. J. O'Malley
Vice President
North American Rockwell
Kennedy Space Center, Florida 32899

Subject: SERVICES RENDERED

Inspection	$ 20.00
Towing charge @ $1.00/mile	300,000.00
Loan of altitude vehicle $20/day plus .08¢ per mile	24,100.00
Battery charge	5.00
Air conditioning @ $5.00/day	25.00
Room and board @ $40.00 each per day	600.00
TOTAL:	$324,750.00

Very truly yours,

GRUMMAN AEROSPACE CORPORATION

George M. Skurla
Vice President

P. S. 2% contractor discount if paid within 30 days.

NASAWATCH

Image Credit: NASA courtesy of Spaceref (see https://moon.nasa.gov/resources/399/apollo-13-presentation/)

Constellation Program

Like Apollo: An Orion capsule & service module plus Altair, providing two spacecraft

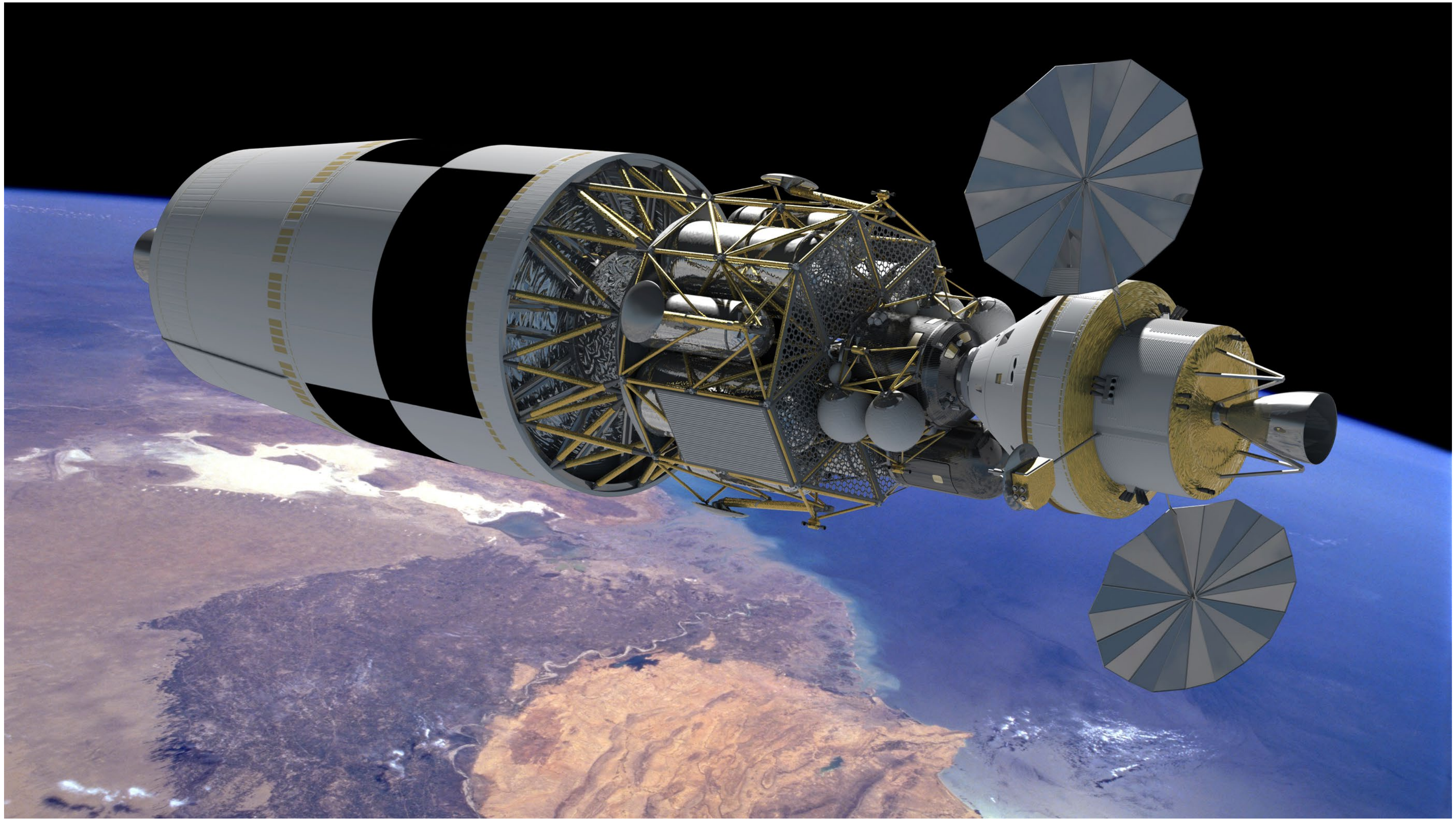


***Image Credit: NASA** (https://www.nasa.gov/images/content/327723main_jsc2007e113278_high.jpg)*

Artemis – The crew is solely reliant upon the Orion and its European Service Module (ESM)

An Apollo 13 like scenario during an Artemis mission would likely result in loss of crew.

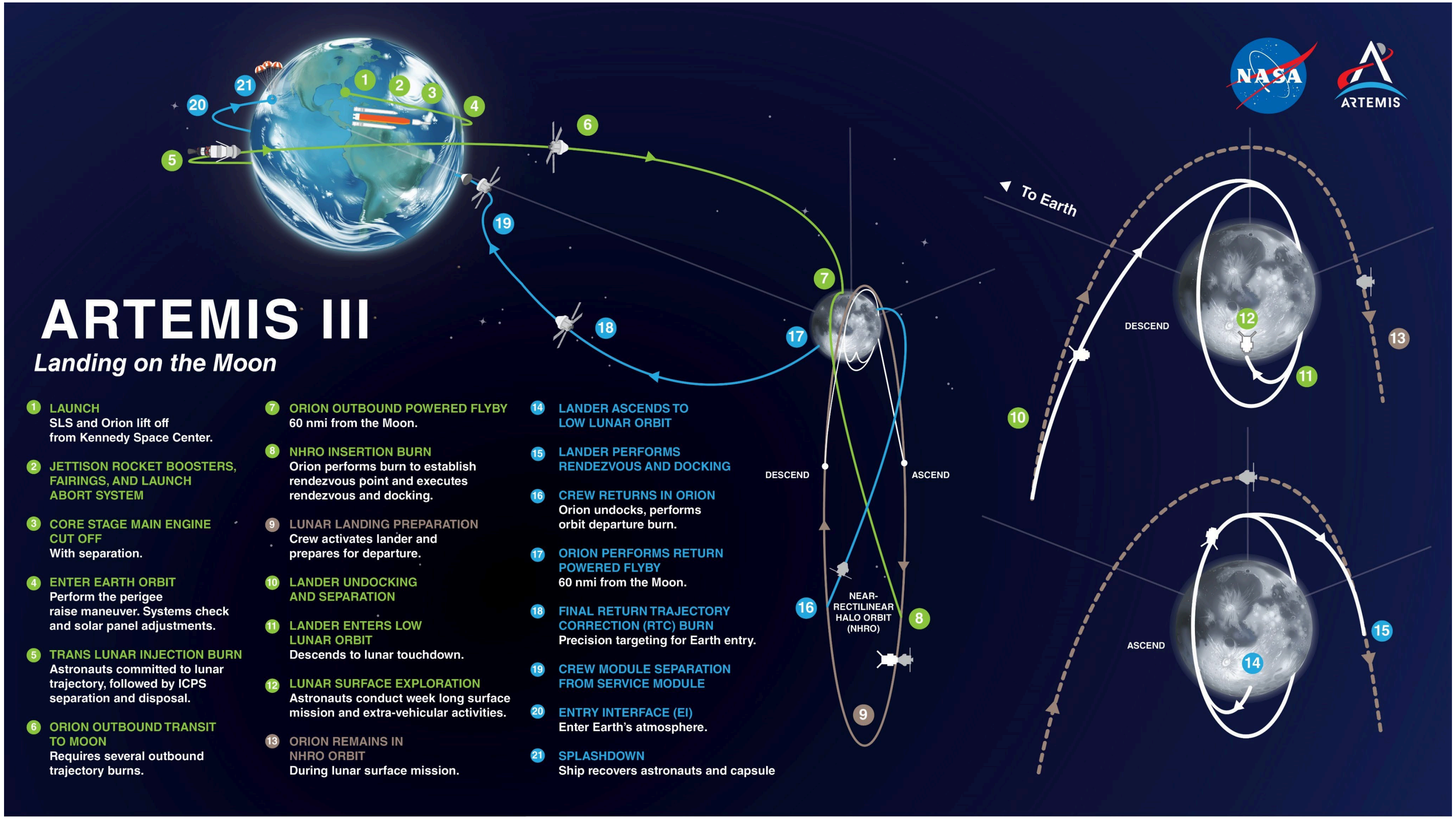


***Image Credit: NASA** (https://www.nasa.gov/sites/default/files/thumbnails/image/artemis_iii_mission_map_2022.jpg)*

Submarines

Submariners initially took to the deep at their own risk and peril

- On September 25, 1925, the submarine USS S-51 was struck by the merchant steamer City of Rome.
- Three of the 36 submariners managed to exit the sub before it sank in 131 feet of water.
- Another submarine skippered by Charles Momsen, who would later rise to the rank of rear admiral, arrived on the scene and found the telltale oil slick and air bubbles of a sunken submarine.
- Momsen later penned a friend, writing:
  - *We tried to contact her, but there was only silence in return. Those of us on the bridge simply stared at the water and said nothing. No one at the time knew anything about the principals of escape and rescue. We were utterly helpless. I myself never felt more useless.*

- Two years later, on December 17, 1927, the USS S-4 was running submerged when it was accidentally rammed by the U.S. Coast Guard Destroyer Paulding and sank.
- Thirty-nine submariners and one civilian were on board.
- All eventually perished inside the stricken S-4 lying just 140 feet below the surface while surface ships circled above.
  - *For nearly three days, the entombed men beat out their pitiful hammer taps of hope. Each hour the taps grew more feeble. Then they stopped altogether.*

From Peter Maas, *The Terrible Hours: The man behind the greatest submarine rescue in history*, HarperCollins Publishers, 1999, pg. 54-55.

Submarines

Submariners initially took to the deep at their own risk and peril

- "As submarine capabilities were gradually introduced in various navies around the world, a common question also emerged: what can be done in the event of a submerged accident that disables the submarine and prevents it returning to the surface?"
  - *For many years the answer was essentially nothing unless the sub sank in very shallow water.*
  - *Over 800 submariners perished in submarine accidents between 1918 and 1939.*
  - *The capability to either escape from a submarine lying on the ocean bottom beneath hundreds of feet of water or to rescue a crew by external means was generally thought not possible.*

- Development of escape and rescue capability was not a priority of the U.S. Navy.
- Submariners took to the deep at their own risk and peril.
- And this was largely accepted.
- Until it wasn't.

Nick Stewart, "Submarine escape and rescue: a brief history," *JMVH*, reprinted articles, Issue 17 No. 1, October 2008 (reprinted with permission of the editors of Seapower Centre – Australia from Semaphore, Issue 07 July 2008) (https://jmvh.org/article/submarine-escape-and-rescue-a-brief-history-2/).

New England Historical Society, "USS Squalus Rescue: World Awaits News of Sailors' Fate," https://www.newenglandhistoricalsociety.com/uss-squalus-rescue-world-awaits-news-sailors-fate/.

Submarines

Escape and Rescue Capabilities Emerged From Tragedy

- Charles Momsem championed submarine escape and rescue
  - *developed a breathing apparatus subsequently called the Momsen Lung that would allow individual submariners to escape from a sunken sub.*
  - *led and participated in efforts to improve deep sea diving capabilities.*
  - *pushed for and led the development, testing, and deployment of a portable rescue chamber that could be lowered to a sunken submarine for extracting the crew and bringing them to the surface.*
- When the USS Squalus sank in 240 feet of water during her sea trials in 1939 on May 23, Momsen led the rescue efforts using the rescue chamber, which also required many dangerous dives by deep sea rescue divers to prepare for and conduct the deployment of the rescue chamber.
- Although 26 men drowned when the engine compartment flooded and caused Squalus to sink, 32 crew members and one civilian were rescued from the forward unflooded section of the submarine.
- The drama that unfolded became widely known in near real time thanks to the telegraph and radio. "The attention of the entire country and civilized world focused on USS Squalus and the rescue attempts that first long night"

Artist John Groth's Concept of a Rescue Chamber Used To Save the Squalus Crew
(Image Credit: United States Navy)United States Navy, "The Rescue of the USS Squalus (SS-92)," Naval History and Heritage Command (https://www.history.navy.mil/our-collections/art/exhibits/conflicts-and-operations/the-rescue-of-the-uss-squalus-ss-192.html).

United States Navy, "USS Squalus (SS-192): The Sinking, Rescue of Survivors, and Subsequent Salvage, 1939," Naval History and Heritage Command, August 15, 2016. https://www.history.navy.mil/content/history/nhhc/research/histories/ship-histories/danfs/s/squalus-ss-192/squalus-ss-192-sinking-rescure-of-survivors-and-salvage.html

New England Historical Society, "USS Squalus Rescue: World Awaits News of Sailors' Fate," https://www.newenglandhistoricalsociety.com/uss-squalus-rescue-world-awaits-news-sailors-fate/

Modern Submarine Rescue Capability

Deep Submergence Rescue Vehicle

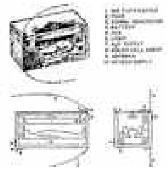
The US Navy's DSRV-1 *Mystic* docked to a *Los Angeles*-class attack submarine
U.S. Navy, Journalist 3rd Class Wes Eplen -
This image was released by the United States Navy with the ID 020425-N-0401E-003

- Submarine rescue capabilities evolved further in the 1960s following the loss of two American nuclear powered submarines, US Ships Thresher and Scorpion, despite both boats being lost in waters that precluded escape or rescue.
- After considering a variety of options, including submarines with in-built escape pods (similar to the Russians) and submarines with front ends that could be blown to the surface, the USN developed the Deep Submergence Rescue Vehicle (DSRV).
- Entering service during the 1970s the DSRV is a manned mini-sub that mates with a disabled submarine's hatch.
- With two built, one is maintained in an operational state so it can be flown in a C-5 cargo plane to a port nearest the disabled submarine. It can then be placed onboard either a modified US or allied submarine.

From: https://jmvh.org/article/submarine-escape-and-rescue-a-brief-history-2/

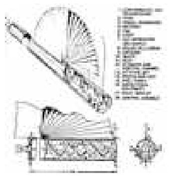
http://www.astronautix.com/r/rescue.html

Provides overview of many rescue concepts dating back to 1959

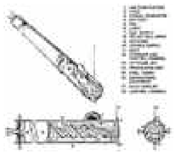


1 Crew Lifeboat American manned rescue spacecraft. Study 1959. One crew lifeboat capsule, separable, not re-entry capable, short duration. Mass per crew 266 kg.

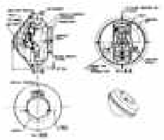
1 Crew Lifeboat Long Term American manned rescue spacecraft. Study 1959. One crew lifeboat capsule, separable, not re-entry capable, long duration. For use on Mars/Venus expedition.



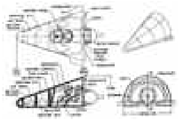
3 Crew Lifeboat Long Term American manned rescue spacecraft. Study 1959. Three crew lifeboat capsule, separable, not re-entry capable, long duration. For use on Mars/Venus expedition. Mass per crew 511 kg.



3 Crew Lifeboat American manned rescue spacecraft. Study 1959. Three crew bailout lifeboat separable, not re-entry capable, short duration. Mass per crew 239 kg.

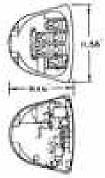


1 Crew Ballistic Re-entry Capsule American manned rescue spacecraft. Study 1960. One crew ballistic re-entry capsule. Orbital escape - no abort capability. Mass per crew 327 kg.



3 Crew Lifting Re-Entry Concept American manned rescue spacecraft. Study 1960. Three crew lifting re-entry capsule. Orbital escape - no abort capability. Mass per crew 434 kg.

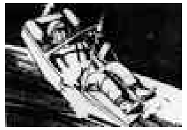
FIRST Re-Entry Glider American manned rescue spacecraft. Study 1960. FIRST (Fabrication of Inflatable Re-entry Structures for Test) used an inflatable Rogallo wing for emergency return of space crew from orbit.



Advanced Manned System 1961 American manned rescue spacecraft. Study 1961. Six crew ballistic re-entry capsule. Orbital escape - abort capability. Mass per crew 548 kg.

LEAP lunar flyer American manned lunar flyer. Study 1961. LEAP was an early 1960's British design for getting disabled astronauts on the lunar surface quickly to lunar orbit for ferrying home.

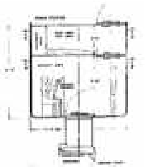
5 Crew Lifeboat American manned rescue spacecraft. Study 1962. Five crew lifeboat capsule, separable, not re-entry capable, short duration. Mass per crew 284 kg.



Paracone American manned rescue spacecraft. Study 1963. The Douglas Paracone was one of the most minimal schemes for bail-out from orbit. The objective was to hit a continental land mass; for such purposes totally manual re-entry operations were used.

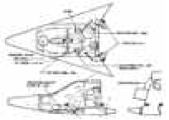
http://www.astronautix.com/r/rescue.html

Provides overview of 31 rescue concepts dating back to 1959

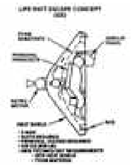


10 Crew Shelter American manned rescue spacecraft. Study 1963. Ten crew emergency shelter capsule, not separable, not re-entry capable, long duration. Mass per crew 301 kg.

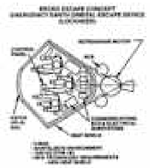
MOOSE American manned rescue spacecraft. Study 1963. MOOSE was perhaps the most celebrated bail-out from orbit system of the early 1960's. The suited astronaut would strap the MOOSE to his back, and jump out of the spacecraft or station into free space.



Re-Entry Escape System American manned rescue spacecraft. Study 1963. One crew lifting re-entry capsule. No abort capability. Mass per crew 1171 kg.



GE Life Raft American manned rescue spacecraft. Study 1966. The GE Life raft was a rigid unpressurized aeroshell. Three crew in space suits with parachutes would strap themselves into the seats.



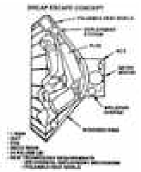
Lockheed EEOED American manned rescue spacecraft. Study 1966. Lockheed's EEOED was a three-crew Discovery-type re-entry vehicle.

Orbital Escape System American manned rescue spacecraft. Study 1966.

SAVER American manned rescue spacecraft. Study 1966. The Rockwell SAVER concept provided return of a single crew member in his ejection seat. A nose cap only the size of the seat absorbed most of the re-entry heat.

AIRMAT American manned rescue spacecraft. Study 1968. Inflatable; space suits required; ejection seat; requires development of flexible heat shield and new materials. Mass per crew 570 kg.

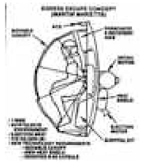
Rib Stiffened Expandable Escape System American manned rescue spacecraft. Study 1968. This Rockwell concept was stowed in a canister. In an emergency, the articulated rib-truss structure would be deployed into a mechanically rigid aeroshell shape.



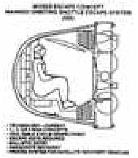
ENCAP American manned rescue spacecraft. Study 1970. The ENCAP encapsulated bailout-from-orbit concept consisted of a folded heat shield. The astronaut would exit his stranded spacecraft and strap into the seat.

http://www.astronautix.com/r/rescue.html

Provides overview of 31 rescue concepts dating back to 1959



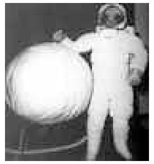
EGRESS American manned rescue spacecraft. Study 1972. The EGRESS space escape system was based on the proven Encapsulated Ejection Seat System developed for the B-58 bomber in the 1960's.



MOSES American manned rescue spacecraft. Study 1975. The General Electric MOSES space rescue concept of the early 1980's took advantage of large re-entry capsules already developed for classified US military projects.

Northrop LBEC American manned rescue spacecraft. Study 1976. Northrop, building on its work on the HL-10 and M2-F3 lifting bodies, proposed a lifting body three-crew lifeboat. The piloted spacecraft would use a parasail for recovery.

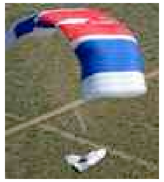
Rockwell SHS American manned rescue spacecraft. Study 1976. The Rockwell Spherical Heat Shield escape concept used a return capsule shell like a Vostok capsule cut in half. Two crew could be returned in a pressurized environment. Mass per crew 220 kg.



Rescue Ball American manned rescue spacecraft. Study 1984. The Personal Rescue Enclosure (PRE) Rescue Ball was an 86 cm diameter high-tech beach ball for transport of astronauts from a spacecraft in distress to the space shuttle.

NASA ACRV American manned spaceplane. Assured Crew Return Vehicle or Astronaut Crew Rescue Vehicle. Study 1986. The early Space Station proposals assumed the facility would be equipped with a 'safe haven' where the crew would wait for a rescue Shuttle in case of emergency.

ESA ACRV European manned spacecraft. Study 1992. As Hermes gradually faded into oblivion, the European Space Agency started to take a closer a look at cheaper and less complicated manned space capsules.



X-38 American manned spaceplane. Lifting body reentry vehicle designed as emergency return spacecraft for International Space Station crew. Crew Return Vehicle prototypesatellite built by, Aerojet (DPS) for NASA.

IRDT Russian manned rescue spacecraft. Inflatable re-entry and descent technology vehicle designed to return payloads from space to the earth or another planet. Tested three times, with only one partially successful recovery.

IRDT 1, 2, 2R Inflatable heatshield technology satellite built by NPO Lavochkin for ESA, Russia. Launched 2000.

Many systems have been studied, few have been tested, essentially none are available today

The Outer Space Treaty & The Artemis Accords

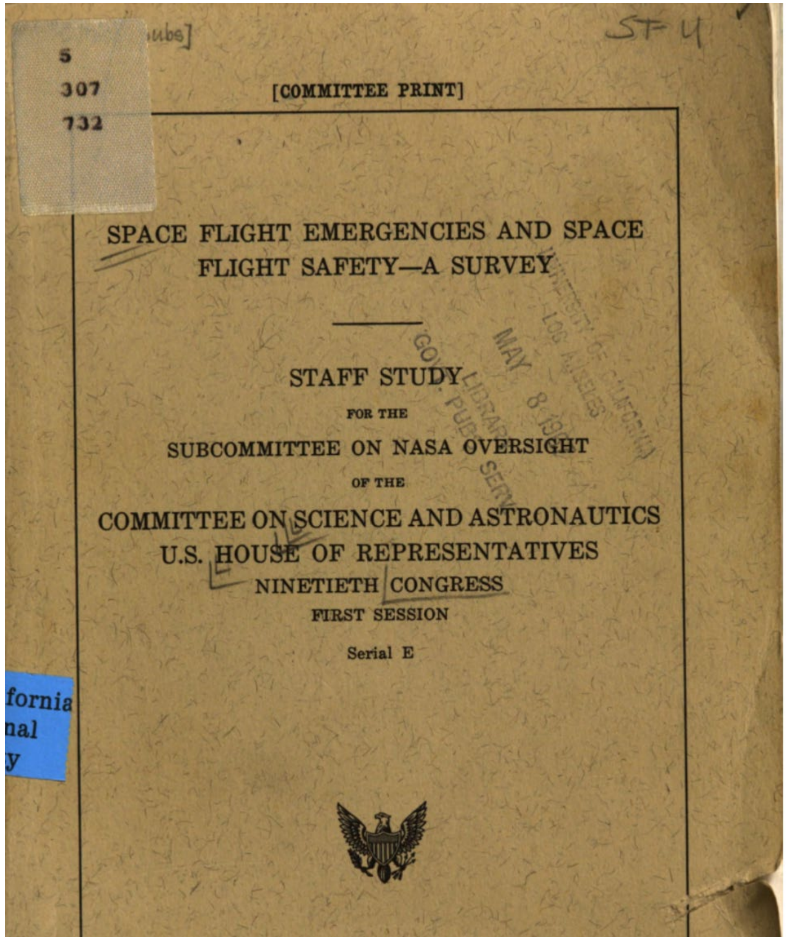
- The Outer Space Treaty entered into force in 1967
  - *Article V alludes to potential need to rescue astronauts in space.*
  - *"In carrying on activities in outer space and on celestial bodies, the astronauts of one State Party shall render all possible assistance to the astronauts of other State Parties."*
- In 1968, a second treaty came into force that is known as the Rescue and Return Agreement of 1968.
  - *This treaty is primarily focused upon the rescue and return of astronauts that have made emergency landings somewhere on Earth.*
- While the Outer Space Treaty requires that nations render all possible assistance during an emergency, it does not require nations to proactively develop capabilities to enable rescue of astronauts in space.

- The Artemis Accords signed in 2020
  - *Section 6 – Emergency Assistance*
    - The Signatories commit to taking all reasonable efforts to render necessary assistance to personnel in outer space who are in distress, and acknowledge their obligations under the Rescue and Return Agreement
- Similar to the Outer Space Treaty, the Artemis Accords do not require Signatories to develop search and rescue capabilities.

Treaties require U.S. to render assistance, but not to develop the capability to do so

Space Flight Emergencies and Space Flight Safety—A Survey

Subcommittee on NASA Oversight of the Committee on Science and Astronautics, U.S. House of Representative, Ninetieth Congress, First Session. ***1967***


[COMMITTEE PRINT]

SPACE FLIGHT EMERGENCIES AND SPACE FLIGHT SAFETY—A SURVEY

STAFF STUDY

FOR THE

SUBCOMMITTEE ON NASA OVERSIGHT

OF THE

COMMITTEE ON SCIENCE AND ASTRONAUTICS

U.S. HOUSE OF REPRESENTATIVES

NINETIETH CONGRESS

FIRST SESSION

Serial E

The committee recognizes that the problem of space flight safety is far more complex than initial press and public discussions would indicate and that solutions to space emergencies, in addition to preventative measures, include ground-based rescue, escape in orbit with or without reentry, on-board repair and replacement and variations thereof.

It believes that it would be unrealistic and contrary to the laws of probability to maintain that the Nation will never require a space rescue and escape capability.

The main question, in the eyes of the committee, is not whether such a capability must be developed but in what forms, at what times and at what costs this capability is to evolve.

https://play.google.com/books/reader?id=Q2UutxrLdqIC&hl=en&pg=GBS.PP1

Space Flight Emergencies and Space Flight Safety—A Survey

Subcommittee on NASA Oversight of the Committee on Science and Astronautics, U.S. House of Representative, Ninetieth Congress, First Session. ***1967***

Much has been said of the need for space flight emergency systems, such as a ground-based rescue system, to go to the immediate aid of astronauts stricken or stranded in orbit, but little of the operational and technological requirements (such as required reaction times) and costs for such systems.

Similarly, others have maintained that the extremely stringent reliability and testing standards preclude the probability of a space emergency which would require either rescue or escape.

The committee believes at this time that the state-of-the-art, financial priorities, the probabilities of certain emergencies occurring at a greater frequency than others, and other factors require that much detailed and intensive analysis and study is still needed before the Nation can embark on development of specific space flight emergency systems required to provide the necessary capability beyond that inherent in present spacecraft to assist astronauts in distress.

https://play.google.com/books/reader?id=Q2UutxrLdqIC&hl=en&pg=GBS.PP1

Space Flight Emergencies and Space Flight Safety—A Survey

Subcommittee on NASA Oversight of the Committee on Science and Astronautics, U.S. House of Representative, Ninetieth Congress, First Session [1967]. ***Conclusions***

1. The replies to the questionnaire (see appendix VIII) contained a wide diversity of opinion as to the best way to cope with future space emergencies and the types of effort which should be continued or initiated.

   Taken as a whole, the replies indicated that the subject of space emergencies is a complex issue and that, while several approaches to escape and rescue are presented, a specific program representing a consensus is not apparent.

2. It is apparent that each NASA manned space flight program to date (Mercury, Gemini) had, as a built-in feature, a strong and effective space flight safety program, emphasizing high equipment reliability and redundancy and mission control.

   A significant segment of aerospace community advocated continued extensions of techniques to improve equipment and mission reliability.

   However, as mission duration increases, some responders noted that repair and replacement becomes more effective and takes its place as a prime technique for planetary missions.

3. A majority of the replying organizations stated that there will be a need for space rescue capability in the future.

   They indicated that there will be a relatively large number of manned earth orbital missions and, hence, a greater need for earth orbit rescue capability than for cislunar or interplanetary rescue.

   A number of the organizations identified on-board escape and reentry devices as potentially useful rescue systems for low earth orbital missions.

4. The two Government agencies, and a few firms, stated that rescue can be realized as a byproduct of a logistics ferry transportation system that will be in demand in the next decade.

https://play.google.com/books/reader?id=Q2UutxrLdqIC&hl=en&pg=GBS.PP1

Space Flight Emergencies and Space Flight Safety—A Survey

*Subcommittee on NASA Oversight of the Committee on Science and Astronautics, U.S. House of Representative, Ninetieth Congress, First Session [1967]. **Recommendations***

1. That, in view of the increasing scope and complexity of planned manned space flight programs and the increasing availability of advanced technology for possible application to space flight safety, the National Aeronautics and Space Administration and the Department of the Air Force continue to devote intensive study effort to the area of space flight safety and to periodically report to the committee on the status and progress of such efforts to insure that the national space programs leave no stone unturned to make our manned space flights as safe as possible.

2. That the National Aeronautics and Space Administration and the Department of the Air Force establish a joint working - level committee or group (with objectives and terms of reference similar to those of the currently existing Department of the Air Force Space Rescue Technical Group) to insure;

that there is no unnecessary duplication between the space safety research programs of the two agencies;

that there exists a total and timely exchange of information between the two agencies in the subject area;

that a compatibility exists in equipment features required to facilitate space flight emergency assistance techniques;

that joint reviews of accidents and emergencies can be promptly and thoroughly conducted;

and that the overall effort of the Government in the area of space safety can be carried out on a coordinated basis.

https://play.google.com/books/reader?id=Q2UutxrLdqIC&hl=en&pg=GBS.PP1

Space Flight Emergencies and Space Flight Safety—A Survey

Subcommittee on NASA Oversight of the Committee on Science and Astronautics, U.S. House of Representative, Ninetieth Congress, First Session [1967]. ***Recommendations***

3. That, in addition to the space flight safety efforts that are integral to specific programs of the two government agencies, there be established and maintained in each agency a separate and unique flight safety group which would be responsible for, among other tasks;

providing separate inputs, on an overall system basis and keyed specifically to the problems of space flight safety, into the design of systems for specific missions;

the proposal and definition of research and development programs specifically devoted to space flight safety (including rescue and escape) and covering the area of inflight experiments on NASA and Air Force missions;

the preparation and organizing, in advance, of procedures and investigating boards of experts for the handling of accidents ;

and the development of an organizational philosophy for space flight safety (similar to the approach which has evolved in aviation flight safety) which would ultimately provide for an independent review and audit of safety provisions and procedures in specific manned space flight programs.

4. That, in the design and development of any future manned space vehicles (including manned ferry or logistics resupply systems), careful consideration be given by the National Aeronautics and Space Administration and the Department of the Air Force to the maximum incorporation of space flight safety requirements in order to develop any possible space rescue or escape capabilities.

https://play.google.com/books/reader?id=Q2UutxrLdqIC&hl=en&pg=GBS.PP1

Lunar Mission Safety and Rescue

MSC-03976; LMSC-A984262B; July 15, 1971 by Lockheed Missiles & Space Company

- If a rescue capability is demanded for the initial manning and activation of an orbiting lunar station, the rescue must originate from the vicinity of Earth.
- The preferred solution is to provide tugs with the initial manning mission with the capability to escape to Earth orbit in the event of a Prime Transport Vehicle or orbiting lunar station failure.
- A minimum of three tugs are required in the lunar area when surface missions are underway:
  - *one dedicated rescue tug in orbit;*
  - *one operational tug in orbit with capability to perform surface rescue if required;*
  - *and one operational/escape tug on the surface.*
- An orbital lunar station capable of serving as a rescue base and safe haven is a necessary part of the proposed escape/rescue plan.
- The crew compartment of the Prime Transport Vehicle must be provided with the capability for autonomous escape to a safe lunar orbit. This requires a minimum delta V capability of 1,000 ft/sec.
- The tug must have the capability to return to Earth orbit from lunar orbit.

- It is strongly concluded that the primary emphasis should be on survival and escape provisions, with rescue required only where self-help cannot bring the endangered crewmen to a permanent safe haven.
- The reaction times for escape are usually much shorter than for rescue - in many cases, minutes or hours vs days.

This study has applicability to Gateway and future lunar surface missions

Apollo Soyuz

History of Space Shuttle Rendezvous JSC – 63400

- Talks were held in 1970 between Soviet and American space officials to explore the possibility of a joint space flight and development of space rescue techniques.
- Discussions expanded over the next two years and led to the Apollo-Soyuz (or Soyuz-Apollo) Test Project (ASTP).
- Programmatic challenges of ASTP included cultural differences, language barriers, use of different atmospheres in the spacecraft, and the development of androgynous docking hardware that would permit space rescue by vehicles of the same or different countries.

Image Credit NASA

https://www.nasa.gov/sites/default/files/images/467434main_astp03_crew_full.jpg

International discussions and partnerships related to rescue are possible

Apollo Soyuz

History of Space Shuttle Rendezvous JSC – 63400

- A Docking Module (DM) was designed as an airlock that would enable the crews to safely acclimatize before transferring between the vehicles since different atmospheres were used.
- The DM performed several other functions as well. These were
  - *1) Serve as a structural adapter between the Apollo legacy probe and drogue docking mechanism and new androgynous docking mechanism (APAS-75),*
  - *2) Carry communications gear compatible with Soyuz frequencies, and*
  - *3) House Earth resources survey equipment for use after the joint part of the international mission ended.*
- One end of the DM was equipped with a Soyuz compatible androgynous docking device (APAS-75), while the other had an Apollo compatible drogue.
- The DM was carried on top of the S-IVB stage of the Saturn IB launcher, in the same manner as the LM was carried in the Saturn V.

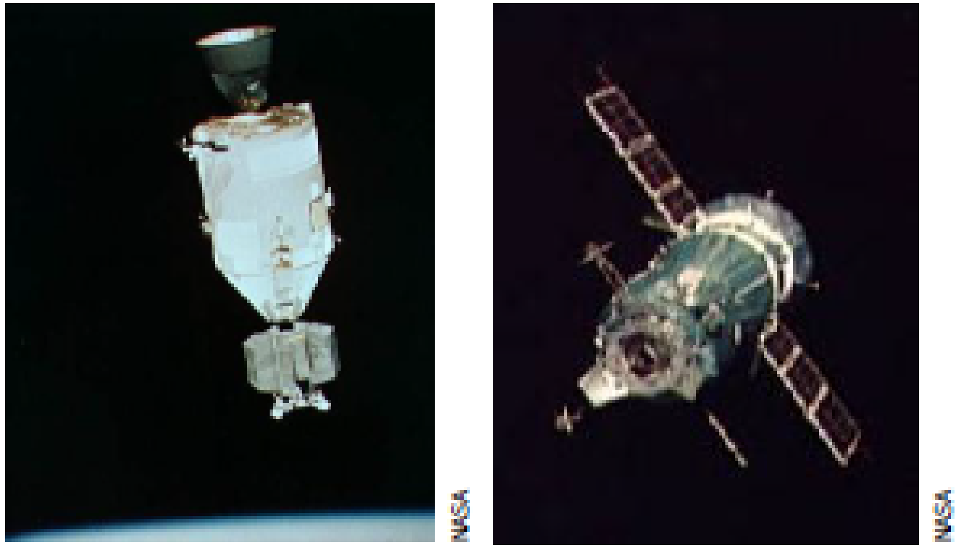


Figure 6.1 Apollo CSM and Docking Module (DM) (left) as seen from Soyuz (left) and Soyuz as seen from Apollo (right) (July 1975).

The docking module was the key flight hardware element required to enable Apollo – Soyuz. It may also serve as an example for a future rescue capability enabler.

Skylab

Skylab concept of operations included a rescue capability with plans and hardware ready

- Each Skylab mission had a rescue plan in case the CSM attached to Skylab was deemed unfit to safely bring the crew home.
- The next Skylab mission would serve as the rescue mission i.e.,
  - *Skylab 3 would rescue Skylab 2*
  - *Skylab 4 would rescue Skylab 3*
  - *While the Skylab 4 crew was on-orbit, a Saturn 1B outfitted with an Apollo CSM was configured to support a rescue if one were required.*
  - *That rocket was positioned out on the launch pad on 5 December and remained there until the Skylab 4 crew returned to earth.*

- The rescue plan was actually initiated during the Skylab 3 mission in 1972, when on August 2^{nd} the on-orbit CSM quad thruster experienced a failure.
- The rescue launch campaign went into full swing for a week, but was waived off on August 10^{th} when it became clear that the on-orbit CSM would be healthy enough to bring her crew home.

See History of Space Shuttle Rendezvous JSC – 63400

Skylab

Skylab concept of operations included a rescue capability with plans and hardware ready

- Skylab was the first U.S. spacecraft equipped with two docking ports.
- The Apollo probe and drogue hardware was used.
- The axial port was the primary port and was used for all dockings.
- The radial port served as a back-up.
- If a rescue mission was required the unusable CSM would be undocked from the axial port and disposed of without a crew onboard, enabling the rescue CSM to use the axial port.
- If the unusable CSM could not be undocked from the axial port the radial port would have been used by the rescue CSM.

- In the event of loss of CSM return to Earth capability, or the crew could not enter the CSM from Skylab, astronauts Brand and Lind were to fly a rescue mission using the next mission's Saturn IB/CSM.
- An additional CSM and Saturn IB launch vehicle was available to rescue the Skylab 4 crew if required.
- Response time varied from 10 to 45.5 days, depending on where the next vehicle was in the launch flow.

See History of Space Shuttle Rendezvous JSC – 63400

Space Shuttle

Requirements

Phase B Program-Level Requirements (1 June 1970)

- Fully reusable two-stage vehicle
- Launched vertically, landed horizontally
- Initial operational capability by late CY 1977
- Payload bay of 15-foot diameter by 60 feet in length with 15,000-pound capacity to a 310nm circular orbit with 55-degree inclination
- 7-day mission duration
- The booster and orbiter shall have a go-around capability during landing
- Launch rates vary from 25 to 75 per year
- Total turnaround time from landing to launch shall be less than two weeks
- A 43-hour turnaround capability shall be provided for rescue missions

- By 1973, four shuttle reference missions were in use for mission planning, vehicle sizing, and subsystem requirements definition, and three of them involved rendezvous.
- There was also a requirement (later waved) for a shuttle to rescue the crew of another shuttle stranded in orbit.
  - *Rescue was to occur no later than 96 hours after launch of the rescue vehicle.*
  - *The rescue shuttle was to be able to phase from either above or below the other shuttle's orbit, depending on the initial phasing at launch.*

History of Space Shuttle Rendezvous, JSC – 63400

In 1973, in the era of having experienced Apollo-13, the concept of rescue was a requirement for the Space Shuttle being developed. This requirement was later waived before the Space Shuttle began flying.

Columbia Accident

Report of the Columbia Accident Investigation Board

To put the decisions made during the flight of STS-107 into perspective, the Board asked NASA to determine if there were options for the safe return of the STS-107 crew. In this study, NASA was to assume that the extent of damage to the leading edge of the left wing was determined by national imaging assets or by a spacewalk. NASA was then asked to evaluate the possibility of:

1. *Rescuing the STS-107 crew by launching Atlantis. Atlantis would be hurried to the pad, launched, rendezvous with Columbia, and take on Columbia's crew for a return. It was assumed that NASA would be willing to expose Atlantis and its crew to the same possibility of External Tank bipod foam loss that damaged Columbia.*
2. *Repairing damage to Columbia's wing on orbit. In the repair scenario, astronauts would use onboard materials to rig a temporary fix. Some of Columbia's cargo might be jettisoned and a different re-entry profile would be flown to lessen heating on the left wing leading edge. The crew would be prepared to bail out if the wing structure was predicted to fail on landing.*

This rescue was considered challenging but feasible. To succeed, it required problem-free processing of Atlantis and a flawless launch countdown. If Program managers had understood the threat that the bipod foam strike posed and were able to unequivocally determine before Flight Day Seven that there was potentially catastrophic damage to the left wing, these repair and rescue plans would most likely have been developed, and a rescue would have been conceivable.

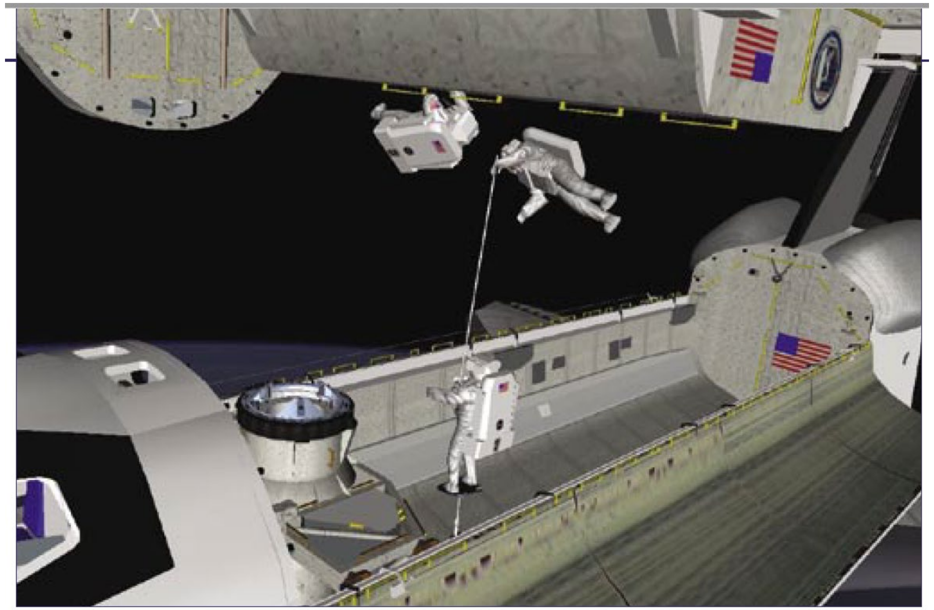


Figure 6.4-2. The rescue option had Atlantis (lower vehicle) rendezvousing with Columbia and the STS-107 crew transferring via ropes. Note that the payload bay of Atlantis is empty except for the external airlock/docking adapter.

A rescue capability could have been improvised, but it was not considered during the time that Columbia was on orbit.

Space Shuttle – Post Columbia

History of Space Shuttle Rendezvous JSC – 63400

- After the loss of Columbia in 2003, each shuttle mission performed inspection of the Thermal Protection System (TPS) to determine if the TPS sustained damage during ascent from External Tank foam shedding.
- The primary means of inspection was the Orbiter Boom Sensor System (OBSS) mounted on the end of the RMS.
- On ISS missions, a +R Bar Pitch Maneuver (RPM) was performed ~600 foot below the ISS to permit ISS crew to photograph the orbiter TPS.
- Photographs provided an additional source of data on TPS integrity.

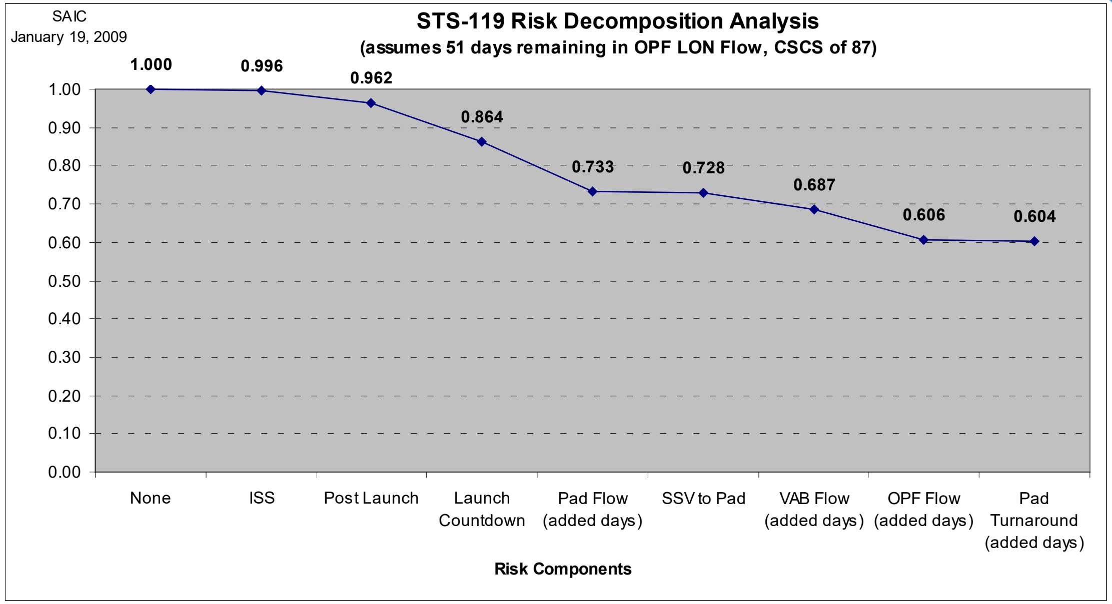
- If TPS damage was detected and was considered to be a safety risk and could not be repaired on-orbit during an EVA, plans were developed to permit a Space Shuttle crew to use the ISS as a safe haven.
- The next Space Shuttle in the launch preparation flow for an ISS mission would be launched to retrieve the crew from the ISS and return them to Earth.

Having a plan for rescuing a crew stranded at the ISS became standard practice, but only after a loss of life event.

Example of ISS Mission Rescue Analysis

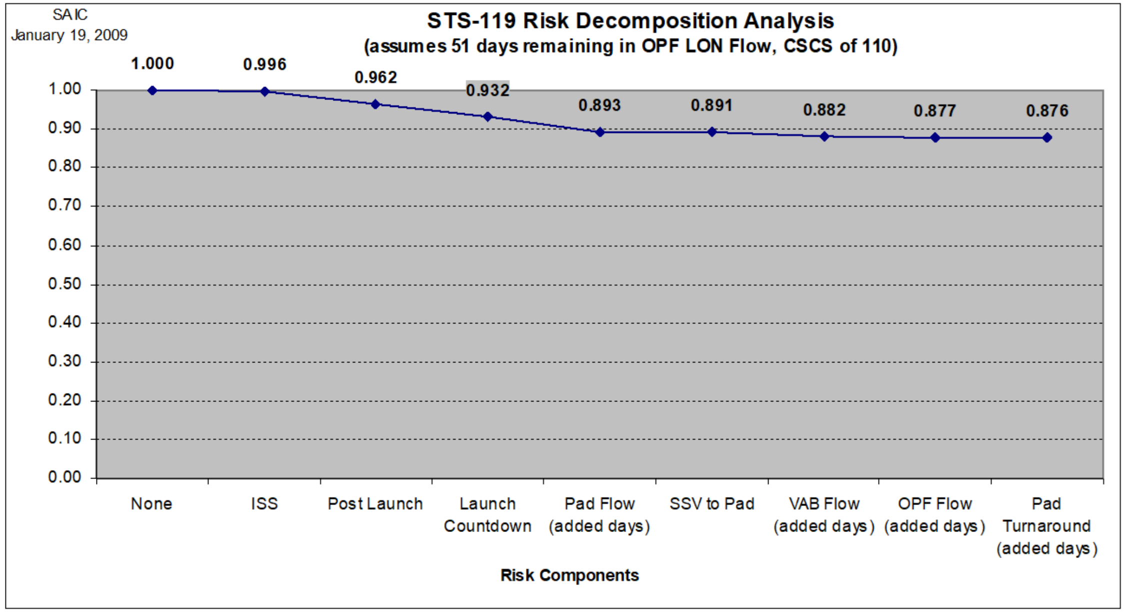
Introduction and Generic Findings

- **The probability of successfully achieving a rescue of a space shuttle crew stranded at the ISS has been estimated using a DES model.**
- **Findings that apply to all missions**
  - **Probability of success is correlated to the CSCS duration of the ISS.**
    - **Greater CSCS duration provides greater probability of success.**
  - **Probability of success is inversely correlated to the remaining days in the OPF flow for the LON mission at the time of the launch of the ISS mission.**
    - **With only a few days remaining in the OPF flow the probability of success is relatively high.**
    - **As flow duration increases, the probability of success decreases.**
  - **No statistical difference has been observed between a Flight Day 4 call-up and a Flight Day 10 call-up. This observation may not apply if the LON orbiter is already at a launch pad when the first vehicle is launched.**



Approach

- The underlying premise of this analysis is that past performance, expert opinion, and the results from other analyses may be used in conjunction with discrete event simulation modeling to help predict the probability of success for the LON plan.
- Used Rockwell Software's Arena discrete event simulation (DES) software
- Simulation model of the ISS LON scenario includes the timeframe from ISS mission launch through rescue (or recovery) and entry of the LON mission.
  - Ground timeline (VAB and Launch Pad) obtained from **STS-117** Delta Flight Readiness Review (**5-30/31-07**) charts and **STS-118** FRR (**7-26/27-07**) charts.
  - Flight timeline provided by NASA (JSC).
- Model is very similar to HST LON simulation model used earlier this year. Some existing coding techniques taken from the space shuttle manifest assessment simulation tool (MAST) and the Constellation-Requirements Assessment Simulation Technique (C-RAST).
- Historical data regarding OPF, MLP, C/T, VAB, Pad, and Launch was used to derive delay probabilities and delay distributions.
- Event probabilities for ascent abort risk, ascent LOCV risk, and entry LOCV risk, along with ISS evacuation risk and ISS LOCV risk based upon STS history.
  - User option to exclude or include in the model runs.
- 5,000 replications run for several different scenarios and assumptions



Space Shuttle – HST Servicing Mission Reinstated

History of Space Shuttle Rendezvous JSC – 63400

- In the aftermath of the 2003 Columbia accident, NASA removed the Hubble Space Telescope (HST) Servicing Mission 4 (SM4) from the Space Shuttle manifest. Reasons cited included concerns that the risk of flying the mission would be too high.
- Successful shuttle missions in 2005 and 2006, along with successful development of TPS inspection and repair methods, led NASA Administrator Michael Griffin to announce in October of 2006 that NASA would fly another servicing mission [STS-125] before the end of the Shuttle Program in 2010.
- NASA re-examined the risk of an HST mission and the use of existing TPS inspection and repair methods.
- Shuttle TPS could be inspected and repaired by the crew using only equipment carried on the orbiter.
- In addition, the concept of using another shuttle to rescue the servicing mission crew was determined to be feasible.
- If un-repairable TPS damage had been detected during the inspections on FD2 (Flight Day 2), Atlantis systems and consumables (such as power and oxygen) could have been managed to keep the crew alive for up to 24 days.
- If the late TPS inspection on FD10 were to detect un-repairable TPS damage, the crew could have been supported for up to 16.5 days.
- A STS-400 rescue of Atlantis by Endeavour could have been conducted no earlier than 15 days and 16 hours after the inspection revealed the damaged TPS.

Space Shuttle – HST Servicing Mission Rescue Conops

History of Space Shuttle Rendezvous JSC – 63400

- The rescue concept required the pre-launch parallel processing of both Atlantis and the rescue orbiter at the Kennedy Space Center.
- The rescue Space Shuttle was on one of the Complex 39 launch pads while Atlantis was launched from the other pad.
- This was a first for the Shuttle Program.
- Although maximum crew awake time was limited to 18 hours to avoid fatigue, this limit could have been waved in a rescue scenario to ensure the safe retrieval and return of the Atlantis crew.
- The nominal rendezvous mission plan for the rescue was a flight day 2 grapple of Atlantis by the rescue orbiter, with the possibility of a flight day 3 or 4 grapple, if permitted by ample propellant margins.
- A flight day 2 grapple was preferred so that the rescue orbiter could reach Atlantis as quickly as possible and provide maximum on-orbit time for the crew transfer to be completed.
- This was the first nominally planned flight day 2 rendezvous and grapple in the Shuttle Program and would have been the first rendezvous of one shuttle with another.

Space Shuttle – HST Servicing Mission Rescue Conops

History of Space Shuttle Rendezvous JSC – 63400

- The rescue involved the transfer by EVA of the seven member Atlantis crew to the rescue orbiter on flight days 3 and 4.
- A total of three EVA transfers from Atlantis to the rescue orbiter would have been performed using the white Extra-vehicular Mobility Unit (EMU) suits.
- Only Atlantis crew members were to participate in the EVAs.
- The four members of the rescue orbiter crew were to remain inside the rescue orbiter.
- At the start of the first EVA participating crew members were to install a translation rope along the RMS of the rescue orbiter.
- Astronauts McArthur, Feustel, and Grunsfeld would have transferred to the rescue orbiter during the first EVA.
- Johnson was to transfer during the second EVA, along with all of the thermal protection system repair hardware.
- The third and final EVA would have transferred Altman, Massimino, and Good.
- Before the last EVA, the remaining crew members on *Atlantis* were to configure the cockpit for the separation and ground commanded deorbit burn.

Space Shuttle – HST Servicing Mission Rescue Conops

History of Space Shuttle Rendezvous JSC – 63400

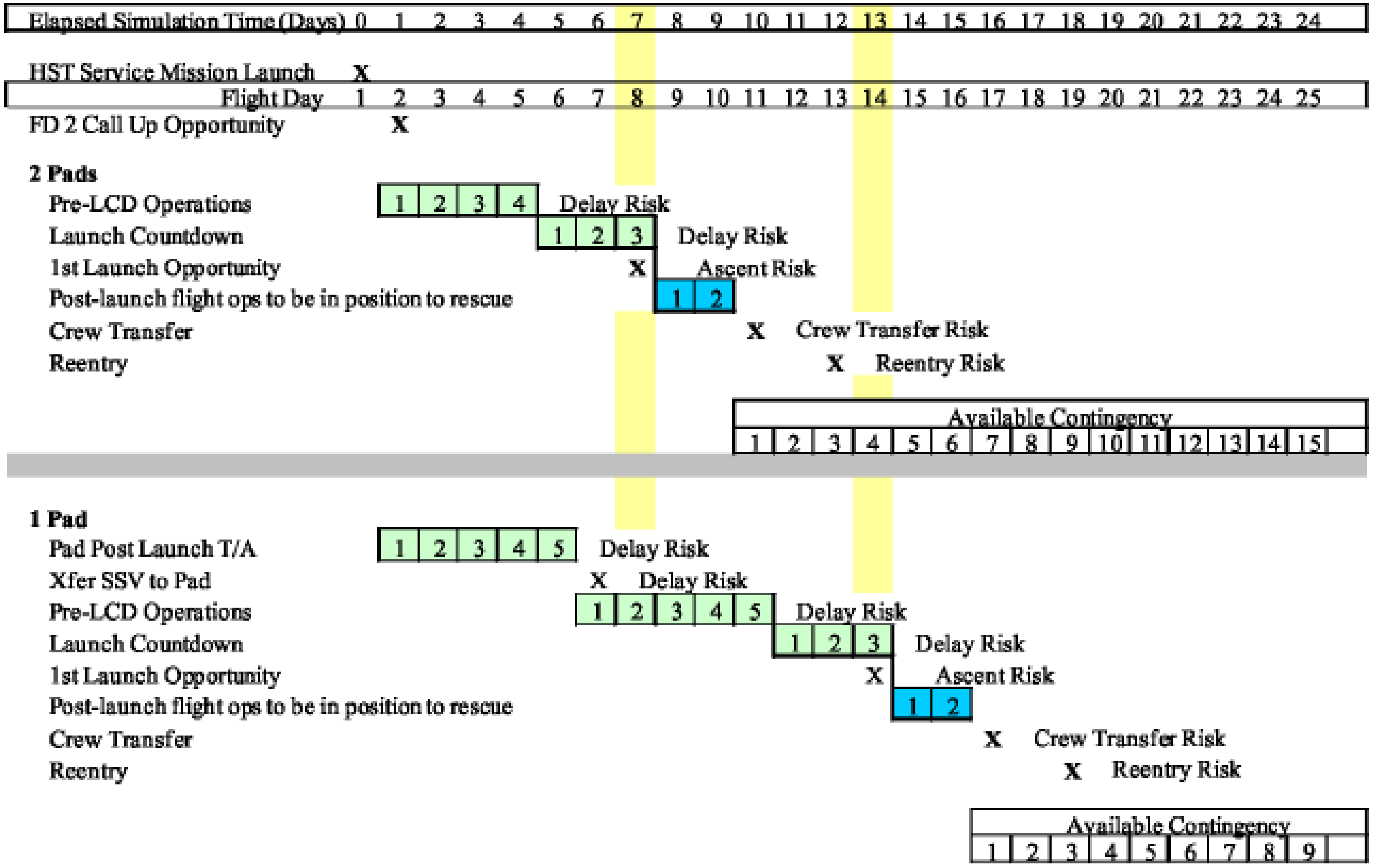
- For the STS-125 HST Servicing Mission, there was a limited amount of time available to perform a crew rescue due to limited consumables (power, oxygen, etc.) available on the Orbiter.
- The success of crew rescue depended upon several factors, including when a problem was identified;
  - *when and what actions, such as powering down, were begun to conserve consumables;*
  - *and where the Launch on Need (LON) vehicle was in its ground processing cycle.*
  - *Crew rescue success also needed to be weighed against preserving the Orbiter's ability to have a landing option in case there was a problem with the LON vehicle*
- The STS-400 rescue mission (Endeavour) was not required and Atlantis landed on Edwards Air Force Base runway 22 on Sunday, May 24, 2009.
- The landing was delayed by two days and moved to Edwards due to unacceptable weather conditions at the Kennedy Space Center.
- On May 31, 2009, Endeavour was moved from pad 39B to pad 39A to prepare for the STS-127 mission that flew in July of 2009.
- Pad 39B was then handed over to the Constellation Program for modification to support the Ares I-X test flight that launched on October 28, 2009.

Example of HST Service Mission Rescue Analysis

https://ntrs.nasa.gov/api/citations/20100005663/downloads/20100005663.pdf

Results from this effort supported NASA's decision to proceed with STS-125, which was successfully completed on May 24th 2009.

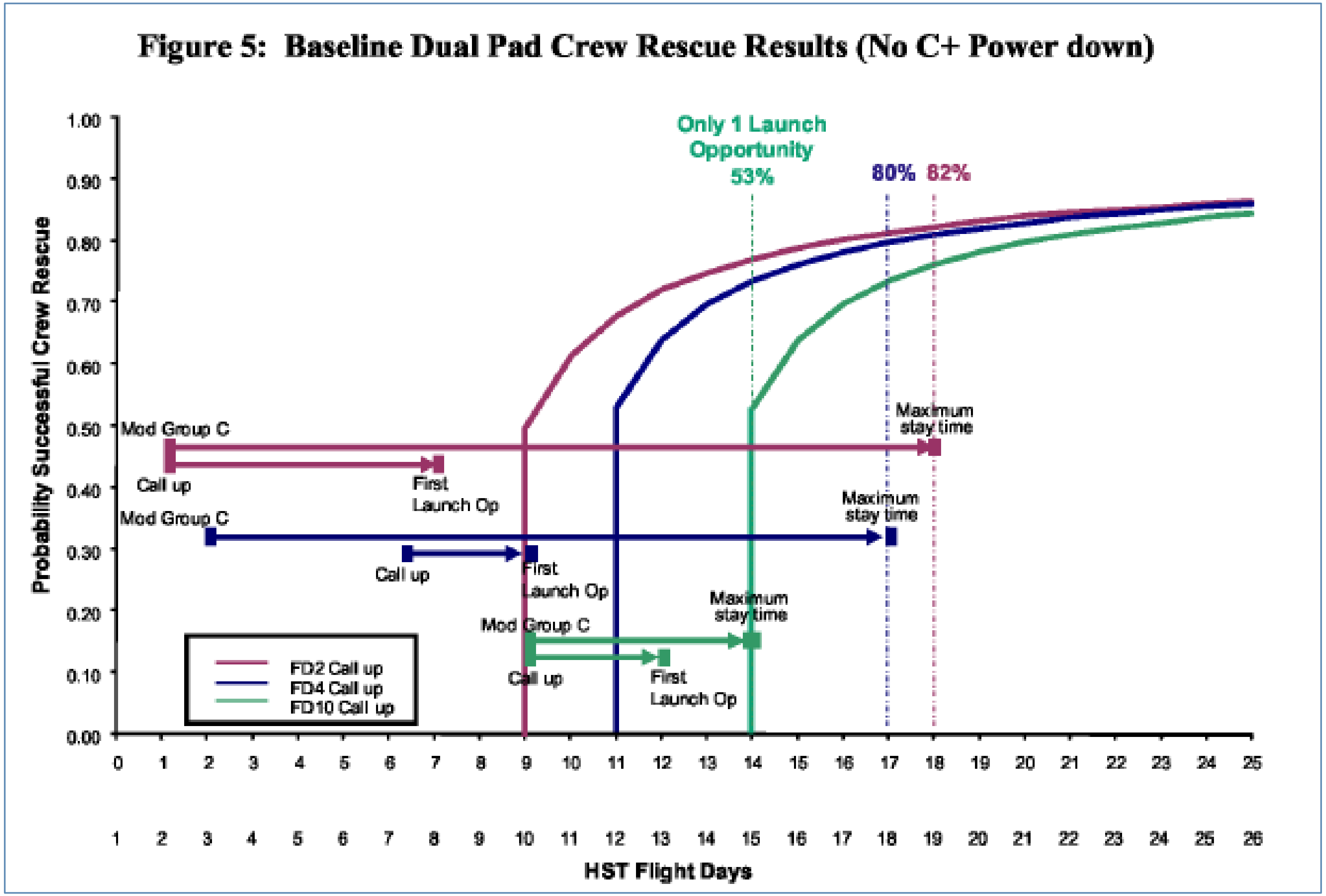
Figure 1: Planned Timelines (Flight Day 2 Call-Up and 24-Day Stay Time)



Example of HST Service Mission Rescue Analysis

https://ntrs.nasa.gov/api/citations/20100005663/downloads/20100005663.pdf

Results from this effort supported NASA's decision to proceed with STS-125, which was successfully completed on May 24th 2009.



International Docking System Standard

A key enabler to space rescue

- In October of 2010, the International Docking System Standard (IDSS) was jointly announced by NASA, the European Space Agency, the Canadian Space Agency, the Japanese Space Agency, and the Russian Federal Space Agency.
- "The IDSS docking interface is fully androgynous about one axis, meaning the interface configuration is capable of mating to an identical configuration," reads the standard.
- Thus, any spacecraft with a compliant international docking system could dock with any other spacecraft with such a docking system.

- "This standard will ease the development process for emerging international cooperative space missions and enable the possibility of international crew rescue missions," said Bill Gerstenmeier, chair of the International Space Station Multilateral Coordination Board and NASA associate administrator for the Space Operations Mission Directorate.
- The latest version of the standard is available publicly on a website (internationaldockingstandard.com) maintained by the five International Space Station Partner Agencies.
- The preface to the standard states, "This International Docking System Standard (IDSS) Interface Definition Document (IDD) establishes a standard docking interface to enable on-orbit crew rescue operations and joint collaborative endeavors utilizing different spacecraft."

https://www.internationaldockingstandard.com/news.html

International Docking System Standard (IDSS)

Implementation

- NASA's implementation of the IDSS is called the NASA Docking System.
- Boeing designed and built a NASA Docking System for their CST-100 Starliner.
- The Orion spacecraft being built by Lockheed Martin will also use a NASA Docking System.
- SpaceX developed their own IDSS based docking system for Crew Dragon.

While all these spacecraft should theoretically be able to dock with one another, there is some uncertainty as to whether or not all of the docking systems currently being implemented are fully androgynous.

Legislative Authorities Related to Space Rescue

Those that mention space rescue seem narrowly focused on the rescue of astronauts at the ISS

42 U.S. Code § 18342

Requirements applicable to development of commercial crew transportation capabilities and services

- Enacted on October 11, 2010
- Pertains mainly to the Multi-Purpose Crew Vehicle (MPCV), which evolved to become Orion.
- As written, it is limited to the rescue of astronauts stranded at the ISS.

51 U.S. Code § 50111

Commercialization of Space Station

As written, it appears to be limited to the rescue of astronauts stranded at the ISS

NASA Authorization Act of 2017

The crew rescue component of the NASA Authorization Act of 2017 is narrowly focused by being under Section 302 (Transportation to ISS) and has been interpreted in practice to mean rescue of astronauts stranded at the ISS

NASA Authorization Act of 2022

Does not appear to mention rescue

Could a government agency be responsible for Space Rescue?

- The most likely agencies at present would either by NASA or the DoD.
  - *Both have space launch capabilities, both develop and operate spacecraft, and both have the wherewithal to develop and employ space rescue capabilities, given a mandate and adequate funding to do so.*
- In the past, NASA has studied and explicitly planned for space rescue, and was prepared to launch space rescues during the Apollo Skylab and Space Shuttle programs.
- DoD provides rescue services for NASA astronauts, on land and at sea, if and when crewed launches abort during ascent or the crew comes down somewhere other than the planned landing/splashdown zone at the end of the mission.
  - *Extending Space Force's rescue responsibilities into space would be synergistic with Space Force's desire to have responsive space capabilities.*
  - *The same rocket that might be needed for crew rescue could instead be outfitted with a ready spacecraft and launched on need to support any of those missions.*
- Potentially both DoD and NASA could be chartered to work together to develop and maintain a space rescue capability. This seems to have been the approach suggested by Congress in 1967.
- A new agency could be created similar to the Coast Guard, i.e., a so-called "Space Guard."
- In-Space SAR could be provided by an international consortium.
- Another alternative would be for the FAA to require companies launching astronauts into space to provide their own rescue capabilities.
  - *However, the FAA is currently prohibited until after October of 2023 from issuing spaceflight regulations intended to protect crew or spaceflight participants.*
  - *This moratorium was put in place in 2004 to prevent government regulations from stifling the nascent commercial human spaceflight industry.*

Implications of having, or not having, a Space Rescue capability

- A Space Rescue operation would have all of the inherent risks of a terrestrial SAR operation.
  - *The rescuers would be at risk of injury and loss of life.*
  - *Additionally, what commonalities might exist between the disabled spacecraft and the rescue spacecraft?*
    - Those would need to be identified and mitigated prior to launch of a rescue mission.
    - An authorized official would have to make the decision as to whether or not to launch the rescue mission

- What are the potential implications of not having space rescue capabilities?
  - *Consider a scenario in which a disabled spacecraft is orbiting earth in which nothing can be done.*
  - *The astronauts will eventually die as the world watches in shock at our inability to rescue them.*
  - *This is analogous to what happened in the early days of submarines. Over 800 submariners perished in submarine accidents between 1918 and 1939.*

Space rescue will entail significant risks, but not having the capability entails risk as well

Policy considerations for Space Rescue

- The Apollo Soyuz Test Project resulting in the docking in space between the U.S. Apollo spacecraft and the Soviet Union's Soyuz spacecraft with the respective crews exchanging pleasantries in space.
  - *This mission came about during the Cold War as a part of the era of détente when President Nixon and Soviet Premier Alexei Kosygin signed an agreement in May of 1972.*
- One can imagine, with all due deference to today's challenging relationships, a similar scenario in which the U.S., Russia, and China would launch their respective spacecraft and practice rendezvous and docking.
  - *This exercise would demonstrate not only the capability to perform space rescue, but might also help establish norms of behavior and cooperation for the sharing of earth orbit.*
- The United States, as the dominant spacefaring nation and leader of the free world, has the wherewithal to establish space rescue capabilities and to do so with a sense of urgency.
- Such capabilities will undoubtably be developed in the future, potentially by our adversaries, with China perhaps already having a head start given their stated launch on need capability for rescue of their astronauts.
- To truly enable a U.S. government space rescue capability, congress would need to appropriate funds for the development of space rescue capabilities and for training and sustainment.

Existing International Capabilities

- Russian and China both have robust launch capabilities and conduct crewed space missions.
- Their rockets and spacecraft, if properly equipped with IDSS docking adapters, could provide rescue capabilities and/or enable their being rescued by like equipped U.S. spacecraft.

- China has put in place a launch on need capability to provide rescue for crews on their new Tiangong space station.
  - *As crews are expected to stay in space for three to six months, the risks of being hit by space debris are growing. According to Shao [Shao Limin, deputy technology manager of the Shenzhou-12 mission], they have a backup rocket and spacecraft ready on the launch pad. "Shenzhou-13 has been transferred to the launch pad as the backup emergency ship at the same time as we transferred Shenzhou-12," he said. If Shenzhou-12 encounters major problem, "we can launch Shenzhou-13 without crew within 10 days for rescue."*

Liu Wei, "Deciphering Shenzhou-12 spacecraft: Docking, space tasks, and trivia," CGTN, June 18, 2021.

Existing U.S. Rockets, Spacecraft, and the International Docking System Standard (IDSS)

That can be leveraged to enable space rescue

- Existing rockets (Atlas, Falcon, etc.) and those in development (Vulcan, New Glenn, Starship, SLS, etc.) provide for the capability to launch an in-space rescue/recovery mission.
- Existing Crew Dragon, Orion, and CST-100 could serve as rescue spacecraft.
- There is the challenge of timeliness, e.g., how long from call-up to launch?
- Developing a launch-on-need capability for space rescue would be synergistic with DoD needs for responsive space launch for reconstitution of space assets, etc.

- NASA advocated for the development and implementation of the International Docking System Standard.
- The preface to the standard announced in October of 2010 states, "This International Docking System Standard (IDSS) Interface Definition Document (IDD) establishes a standard docking interface to enable on-orbit crew rescue operations and joint collaborative endeavors utilizing different spacecraft."
- If installed on all crewed spacecraft, then any spacecraft with an IDSS compliant docking adapter could serve as a rescue spacecraft for another similarly equipped spacecraft.

Technologies are available today to begin implanting an in-space rescue/recovery capability

Conditions under which space rescue would be possible or not possible

Conditions Required for Rescue

- Situational awareness by rescue forces
  - *Knowledge that a rescue is needed*
- The crew must be alive
  - *A spacecraft system failure, potentially caused by an orbital debris strike, that knocks out partial functionality of the spacecraft without killing the crew*
- Capability to launch a rescue mission in a timely fashion (synergistic with responsive launch)
- Capability to rendezvous with the disabled spacecraft
- Capability to transfer the crew from the disabled spacecraft to the rescue spacecraft
  - *By establishing a direct docking (preferred)*
  - *By spacewalks*

Conditions in which Rescue not Possible

- Lack of situational awareness
- Crew killed instantly or in a very short timeframe
- Inability to launch a rescue mission in a timely fashion (lack of responsive launch capability)
- Inability to rendezvous with the disabled spacecraft
- Inability to transfer the crew

Space Rescue Scenario

Space Capsule Disabled in LEO

- Spacecraft: Orion, Crew Dragon, CST-100, Russia's Soyuz, China's Shenzhou, India's Gaganyaan
- Disabled in LEO and unable to return safely to earth. Disabled due to any number of reasons including, but not limited to:
  - *MMOD strike*
  - *Avionics failure*
  - *Engine failure*
- Can support crew for limited duration
- May or may not be going to or coming from the ISS or some other nation's commercial space station

- Current Rescue Options
  - *Rescue themselves by going to an existing space station and waiting for eventual transportation back to earth*
    - Limitations
      - *Must be capable of executing a rendezvous*
      - *Must be capable of docking with space station*
- Conceptual rescue options
  - *Launch of a rescue mission*
    - Requirements
      - *Rescue spacecraft that can be launched in a timely fashion*
      - *Sufficient Delta-V to rendezvous with, and depart from distressed spacecraft, and to reenter*
      - *Capable of transferring crew from distressed spacecraft to rescue spacecraft either via direct docking or station keeping & EVA*
  - *Activation of an on-orbit rescue capability*
    - Potentially a robotic spacecraft with the ability to rendezvous and dock with a distressed spaceship and effect transfer of the crew from the distressed ship to the rescue robotic ship. Then could maneuver to a station and transfer the crew to the station, or alternatively have the capability to return to earth.

Current option is highly limited. Significant effort required to enable other rescue capabilities.

Space Rescue Scenario

Orion disabled in Cis-Lunar Space Beyond LEO During Artemis Missions

- Spacecraft: Orion
- Disabled in Cis-Lunar space and unable to return safely to earth.
- Can support crew for limited duration
- Loss of crew during the Artemis II mission would likely
  - *Raise questions as to why NASA had not learned from Apollo history and studies performed in the 1960s-70s*
  - *Cause a significant delay to plans for returning to the moon and could potentially cause those plans to be scrapped entirely*

- Current Rescue Options – Essentially none
- Conceptual rescue options
  - *Have a second spacecraft or "lifeboat" allowing the crew to rescue themselves*
  - *Launch of a rescue mission*
    - Requirements
      - *Rescue spacecraft that can be launched in a timely fashion*
      - *Sufficient Delta-V to rendezvous with, and depart from distressed spacecraft, perform TEI and to reenter*
      - *Capable of transferring crew from distressed spacecraft to rescue spacecraft either via direct docking or station keeping & EVA*
  - *Activation of an in-space rescue capability orbiting in Cis-Lunar Space*
    - Potentially a robotic spacecraft with the ability to rendezvous and dock with a distressed spaceship and effect transfer of the crew from the distressed ship to the rescue robotic ship. Then could maneuver to a station and transfer the crew to the station, or alternatively have the capability to return to earth.

Significant effort required to enable self-rescue or external rescue capabilities

Recommendations

2022 Space Safety Compendium – Guiding the Future of Spaceflight

https://aerospace.org/sites/default/files/2023-03/SSI_Compendium_2022_v1-1_1.pdf

Recommendation 5.4:

Address the in-space rescue capabilities gap.

Government, commercial, and international organizations should account for and develop proactive capabilities for in space rescue. Article V of The Outer Space Treaty (1967) alludes to the potential need to rescue astronauts in space. It says, "In carrying on activities in outer space and on celestial bodies, the astronauts of one State Party shall render all possible assistance to the astronauts of other State Parties." It does not require nations to proactively develop capabilities to enable rescue of astronauts in space nor does a second treaty, the Rescue Agreement of 1968, which focuses on the rescue and return of astronauts that have made emergency landings somewhere on Earth.

Recommendation 5.5:

Ensure that operators utilize common docking systems for spacecraft.

This can support and improve in-space rescue efforts. In October 2010, NASA, the European Space Agency, the Canadian Space Agency, the Japanese Space Agency, and the Russian Federal Space Agency jointly developed the International Docking System Standard (IDSS), derived in part from the Apollo-Soyuz test project. The preface to the standard states, "This International Docking System Standard (IDSS) Interface Definition Document (IDD) establishes a standard docking interface to enable on-orbit crew rescue operations and joint collaborative endeavors utilizing different spacecraft." Adhering to this standard will mean that any spacecraft with a compliant international docking system can dock with any other spacecraft with such a docking system. It is important to ensure that all crewed spacecraft have an IDSS-compliant docking adapter, so they can easily dock with rescue spacecraft.

Recommendation 5.6:

Integrate rescue plans into launch plans.

Having the ability to integrate a rescue spacecraft with the next available rocket ready to launch could provide a modest rescue capability for distressed spacecraft in Earth orbit. Since orbital launches are occurring with increasing frequency worldwide, there is, on average, a rocket within approximately three days of launch at any given time of the year. If rescue plans were integrated into launch plans, rockets sitting on the launch pad could be utilized for in-space rescue as well. This requires prelaunch determination of the various vehicles' orbit compatibility so that there are no crashes. Another factor that should be considered is whether there is enough propulsive capability onboard the rescue spacecraft to dock in the necessary orbit and accomplish a successful rendezvous.

References

References

- Federal Aviation Administration, "Report to Congress: FAA Evaluation of Commercial Human Space Flight Safety Frameworks and Key Industry Indicators," October 2016, p. 7.
- Koller, K.S. and Nield, G.C., "Human Spaceflight Safety: Regulatory Issues and Mitigating Concepts," The Aerospace Corporation's Center for Space Policy and Strategy, November 2020.
- Federal Aviation Administration, "New Regulations Govern Private Human Space Flight Requirements for Crew and Space Flight Participants," Office of Commercial Space Transportation. March 27, 2020 (https://www.faa.gov/about/office_org/headquarters_offices/ast/human_space_flight_reqs/).
- 14 CFR Parts 401, 415, 431, 435, 440 and 460, Human Space Flight Requirements for Crew and Space Flight Participants; Final Rule. Section 7, Crew Notifications.
- Dwayne A. Day, "Spooky Apollo: Apollo 8 and the CIA," The Space Review, December 3, 2018 (https://www.thespacereview.com/article/3617/1).
- Joel Achenbach, "Apollo 8: NASA's first moonshot was a bold and terrifying improvisation," Washington Post, December 21, 2018 (https://www.washingtonpost.com/history/2018/12/20/apollo-nasas-first-moonshot-was-bold-terrifying-improvisation/).
- Richard Hollingham, "The NASA mission that broadcast to a billion people," BBC, December 21, 2018 (https://www.bbc.com/future/article/20181220-the-nasa-mission-that-broadcast-to-a-billion-people).
- Joel Achenbach, "Apollo 8: NASA's first moonshot was a bold and terrifying improvisation," Washington Post, December 21, 2018 (https://www.washingtonpost.com/history/2018/12/20/apollo-nasas-first-moonshot-was-bold-terrifying-improvisation/).
- Jack Gould, "TV: Millions of Viewers End Vigil for Apollo 13," The New York Times, April 18, 1970 (https://www.nytimes.com/1970/04/18/archives/tv-millions-of-viewers-end-vigil-for-apollo-13-unusual-color.html).
- Nick Stewart, "Submarine escape and rescue: a brief history," JMVH, reprinted articles, Issue 17 No. 1, October 2008 (reprinted with permission of the editors of Seapower Centre – Australia from Semaphore, Issue 07 July 2008) (https://jmvh.org/article/submarine-escape-and-rescue-a-brief-history-2/).
- New England Historical Society, "USS Squalus Rescue: World Awaits News of Sailors' Fate," https://www.newenglandhistoricalsociety.com/uss-squalus-rescue-world-awaits-news-sailors-fate/.
- Peter Maas, *The Terrible Hours: The man behind the greatest submarine rescue in history*, HarperCollins Publishers, 1999, pgs. 54, 55.
- United States Navy, "USS Squalus (SS-192): The Sinking, Rescue of Survivors, and Subsequent Salvage, 1939," Naval History and Heritage Command, August 15, 2016. (https://www.history.navy.mil/content/history/nhhc/research/histories/ship-histories/danfs/s/squalus-ss-192/squalus-ss-192-sinking-rescure-of-survivors-and-salvage.html).
- New England Historical Society, "USS Squalus Rescue: World Awaits News of Sailors' Fate," (https://www.newenglandhistoricalsociety.com/uss-squalus-rescue-world-awaits-news-sailors-fate/).

References

- United States Navy, "The Rescue of the USS Squalus (SS-92)," Naval History and Heritage Command (https://www.history.navy.mil/our-collections/art/exhibits/conflicts-and-operations/the-rescue-of-the-uss-squalus-ss-192.html).
- International Submarine Escape and Rescue Liaison Office (https://ismerlo.org/).
- Encyclopedia Astronautica, "Rescue" (http://www.astronautix.com/r/rescue.html).
- NASA, History of Space Shuttle Rendezvous, JSC-63400, Revision 3, Mission Operations Directorate, Flight Dynamics Division, October 2011, p. 73.
- Shayler, David. J., *Space Rescue: Ensuring the Safety of Manned Spaceflight*, Springer, 2009, pp. 10-11.
- NASA, History of Space Shuttle Rendezvous, JSC-63400, Revision 3, Mission Operations Directorate, Flight Dynamics Division, October 2011, chapter 5.
- Muratore, J. "Space Rescue," NASA, 2007 (https://ntrs.nasa.gov/api/citations/20070025530/downloads/20070025530.pdf).
- Jerry L. Ross with John Norberg, *Spacewalker: My Journey In Space And Faith As NASA's Record-Setting Frequent Flyer*, Purdue University Press, 2013, p. 205.
- Merryl Azriel, "Space Walker: The Story of Astronaut Jerry Ross," interview and book review in Space Safety Magazine, Issue 8, Summer 2013.
- Gehman Jr. Harold W., et al. "Columbia Accident Investigation board report volume 1." (2003).
- Warren E. Leary, "NASA Chief Affirms Stand On Canceling Hubble Mission" New York Times, January 29, 2004 (https://www.nytimes.com/2004/01/29/us/nasa-chief-affirms-stand-on-canceling-hubble-mission.html).
- Hamlin, Teri L., Michael A. Canga, and Grant R. Cates. "Hubble space telescope crew rescue analysis," Proceedings of the 10th International Probabilistic Safety Assessment & Management Conference, 2010.
- Liu Wei, "Deciphering Shenzhou-12 spacecraft: Docking, space tasks, and trivia," CGTN, June 18, 2021.
- International Space Station Partner Agencies, "News and Press Releases," October 2010, (https://www.internationaldockingstandard.com/news.html).
- Space Coast Daily, "Boeing Starliner Installs NASA Docking System Cover on CST-100 Starliner Spacecraft," January 17, 2021 (https://spacecoastdaily.com/2021/01/boeing-starliner-installs-nasa-docking-system-cover-on-cst-100-starliner-spacecraft/).
- National Aeronautics and Space Administration, "Crew Transportation With Orion: Educator Guide," NP-2020-02-2805-HQ (https://www.nasa.gov/sites/default/files/atoms/files/np-2020-02-2805-hq.pdf).
- National Aeronautics and Space Administration, "Sealed with Care – A Q&A," August 3, 2020 (https://www.nasa.gov/feature/glenn/2020/sealed-with-care-a-qa).

References

- NASA Spaceflight.com, "Should SpaceX Vehicles Have Androgynous Docking Ports?" (https://forum.nasaspaceflight.com/index.php?topic=50541.0;all).
- Muratore, J. "Space Rescue," NASA, 2007 (https://ntrs.nasa.gov/api/citations/20070025530/downloads/20070025530.pdf).
- National Aeronautics and Space Administration, "Space Stations Need Lifeboats, Too," May 1, 2014
- (https://www.nasa.gov/content/new-craft-will-be-americas-first-space-lifeboat-in-40-years/).
- William Harwood, "Final two passengers named for first all-civilian mission to orbit earth," SpaceNews, March 30, 2021 (https://spaceflightnow.com/2021/03/30/final-two-passengers-named-for-first-all-civilian-mission-to-orbit-earth/).
- International Association for the Advancement of Space Safety (http://iaass.space-safety.org/reports/).
- Muratore, J. "Space Rescue," NASA, 2007 (https://ntrs.nasa.gov/api/citations/20070025530/downloads/20070025530.pdf).
- Jason Rainbow, "MEV-2 servicer successfully docks to live Intelsat satellite," SpaceNews, April 12, 2021 (https://spacenews.com/mev-2-servicer-successfully-docks-to-live-intelsat-satellite/).
- Piskorz, D. and Jones, K.J., "On-Orbit Assembly of Space Assets: A Path to Affordable and Adaptable Space Infrastructure," The Aerospace Corporation's Center for Space Policy and Strategy, February 2018.
- McKinley, C., Lt. Col., The Guardians of Space: Organizing America's Space Assets for the Twenty-First Century," Aerospace Power Journal, Spring 38 (2000). Maxwell AFB, Alabama.
- Ziarnick, B.D., Capt., "The US Space Guard: Institutional Support to Space Commerce," in L. Morris, K.J. Cox (eds) Space Commerce – The inside story by the people who are making it happen, 2010, pp. 332-355.
- Bennet, J.C., Proposing a 'Coast Guard' for Space, The New Atlantis – A Journal of Technology & Society, Winter (2011).
- Silver Shield Industries LLC, "Sparrow," (https://www.silvershieldindustries.com/sparrow).
- Harwood, Jay et al. "Concept for orbiting micro habitats – Abraham's oasis in the stars," Paper abstract, 72nd International Astronautics Congress 2021.
- Anna Crowley Redding, *Elon Musk: A Mission to Save the World*, Feiwell and Friends Macmillan Publishing Group, 2019, pp. 229-230.
- Rovetto, R.J., "Resurrecting Spaceguard: Concepts for a Coast Guard of Space," 68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017.
- Space Flight Emergencies and Space Flight Safety—A Survey, Subcommittee on NASA Oversight of the Committee on Science and Astronautics, U.S. House of Representatives, Ninetieth Congress, First Session, 1967, (https://play.google.com/books/reader?id=Q2UutxrLdqIC&hl=en&pg=GBS.PP1).