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THE IN-SPACE RESCUE CAPABILITY GAP

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THE AEROSPACE CORPORATION

SPACE SAFETY INSTITUTE SERIES

AEROSPACE

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Summary

The United States government and commercial spaceflight providers have no plans in place to conduct a timely rescue of a crew from a distressed spacecraft in low Earth orbit, or anywhere else in space. Without rescue plans and dedicated resources, today's space travelers will journey at their own risk. U.S. rules and regulations governing commercial spaceflight simply require launch service and space travel providers to inform the crew and passengers that there are risks. The United States, however, as the world's greatest space faring nation, has the wherewithal to develop and employ effective in-space rescue capabilities if it chooses to do so. This paper seeks to raise awareness of the need to revisit space rescue policies and close capability gaps through historical analogs, such as the ancient maritime explorers that embarked upon epic journeys with multiple ships, effective submarine rescue operations, and the rich history of human spaceflight. Potential solutions to improve safety during space travel are identified and policy options are discussed.

Introduction

The lessons of Apollo, Skylab and the space shuttle with respect to the rescue of astronauts in space seem to have been forgotten as the United States enters a new era of space flight that includes commercially provided spacecraft, space tourism, and the return of U.S. astronauts to the moon. Apollo 13 demonstrated the lifesaving properties of two spacecraft capable of sustaining the crew during the journey to the moon. In similar fashion, the great maritime explorers such as Ferdinand Magellan sailed with multiple ships. NASA's Artemis missions, however, will use a single spacecraft for transiting the crew between the Earth and lunar orbit. During all Skylab missions and the final space shuttle Hubble Space Telescope servicing mission, NASA had rescue rockets and spacecraft ready in the event that an on-orbit spacecraft were to be disabled in space. Today, there are no plans in place for such rescues when the SpaceX-crewed Dragon is launched. Likewise, when the Navy began to employ submarines, there was initially no capability to rescue survivors from a sunken sub. This shortfall was only addressed after many submariners perished.

The present posture, that of not planning for in-space rescue and not having responsive in-space rescue capabilities, needs to be addressed before the need for a rescue materializes. Not after. Potential solutions are available and need to be established with a sense of urgency. Key enablers of in-space rescue include ensuring that all crewed spacecraft have common docking mechanisms, timely availability of a rescue spacecraft or a safe haven to escape to, and organizational entities—government, commercial, or international—chartered and sufficiently resourced to plan for, train for, and conduct in-space rescues.

Commercial Space Travel and Tourism

The era of NASA astronauts flying on commercially provided spacecraft has begun, and the era of private citizens traveling in space is about to begin. NASA now relies upon commercial crew space transportation systems to transport astronauts to and from the International Space Station (ISS). SpaceX has already begun these commercial crew ISS missions and Boeing plans to be doing so in the near future. SpaceX has announced multiple missions to space that will carry private citizens—space tourists. These include Inspiration4, planned for later this year; Axiom 1, planned for 2022 followed by additional missions for Axiom; and dearMoon, planned for 2023. Inspiration4 will comprise private citizens orbiting in low Earth orbit (LEO) for up to four days. The Axiom missions will take private citizens to the ISS, and dearMoon will take private citizens on a trip around the moon. More are sure to follow if these are successful.

The FAA is responsible for licensing U.S. commercial crewed space missions and produces the regulations that govern private human space flight. Unlike civil aviation where the FAA plays an active role in regulating safety, the FAA is currently prohibited until after October of 2023 from issuing spaceflight regulations intended to protect crew or spaceflight participants.[1] This moratorium was put in place in 2004 to prevent government regulations from stifling the nascent commercial human spaceflight industry. However, the development of voluntary industry actions to improve safety was encouraged.[2] The rules that are in place "maintain FAA's commitment to protect the safety of the uninvolved public and call for measures that enable passengers to make informed decisions about their personal safety."[3] Note the emphasis on *protecting the uninvolved public*. In accordance with the Commercial Space Launch Amendments Act, the FAA policy does not stress the safety of the space traveler; it simply mandates that the traveler be informed that there is risk. "The notification requirement requires only that an operator inform the crew that risks exist, not that it identify all potential operational and design hazards."[4] One has to wonder if the current policy is adequate for space tourists who may not be in position to comprehend the full breadth and scale of risks.

The risks involved in space travel are many, and they are magnified by the fact that there are no plans and attendant capabilities in place for the timely rescue of a crew from a disabled spacecraft in LEO or anywhere else in cis-lunar space. None. That is not to say that such plans and capabilities cannot be developed. They can be. The question becomes, should they? And if so, who should develop them, and who should be responsible for conducting space rescues?

These are questions not just with respect to Orion, Crew Dragon, and CST-100, three spacecraft that are in or nearing operational status. SpaceX is also developing their Starship Super Heavy for crewed missions to the moon and Mars. SpaceX, Blue Origin, and Dynetics proposed human landing systems for taking astronauts to the lunar surface and back. Sierra Nevada has aspirations for crew-rating their Dream Chaser, and Rocket Lab has recently announced its own plans for taking people to space. Internationally, Russia and China each have their own crewed spacecraft and soon India will have one as well. Other nations and commercial companies will likely develop crewed spacecraft in the future.

Historical analogs that may prove instructive for informing a dialog on space rescue policy include maritime explorers, submarine escape and rescue capabilities, and of course the history of U.S. human space flight, which includes numerous space rescue studies, an actual space rescue situation, and the preparations for other space rescues that thankfully were not needed.

Maritime Explorers

When the great maritime explorers—such as Christopher Columbus, Ferdinand Magellan, James Cook, and others—set sail on daring and dangerous multi-year journeys, there was little hope of being rescued. One can well imagine that volunteer sailors for such missions were informed that there would be mortal hazards. The expeditions typically sailed with multiple ships. Columbus sailed with three ships and Magellan sailed with five ships. Having multiple ships offered a measure of safety since one ship in the flotilla could come to the aid of another. Single-ship expeditions, such as John Cabot (1497) and James Cook (1768), were exceptions and sailed at increased risk. For example, HMS Endeavour carrying James Cook during his lone single-ship mission ran aground on June 11, 1770 on the Great Barrier Reef. The crew eventually managed to free the ship and beach it a week later in the mouth of what is now the Endeavour river. It took seven weeks to repair the ship and Cook set sail again on August 22, 1770. His subsequent exploration missions were with two and then three ships.

Apollo 8 – A Single-Ship Mission

Apollo 8 is the lone single-ship mission that has taken a crew beyond LEO. It was originally to have been a systems checkout flight in Earth orbit for the Apollo command and service module (CSM). However, in August of 1968, the CIA told NASA that the Soviets were planning a crewed lunar orbit mission by year end. In response, NASA accelerated the Apollo 8 mission and changed it to a lunar orbit moon mission. In a declassified October 1968 report, CIA Deputy Director for Science and Technology Carl Ducket referred to the Apollo-8's mission as "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."[5] The lunar lander was not available yet, so there was no chance of a lunar landing. 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.[6] 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 mission launched in December and on Christmas Eve, the crew of three—Commander Frank Borman, Jim Lovell, and Bill Anders—read from the Book of Genesis as they orbited the moon. NASA estimated that a billion people, a quarter of the world's population, would be listening by radio or tuning in by TV.[7] But the mission was far from over.

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 to be critical to all future lunar missions as well. The burn occurs on the far side of the moon, and if it fails the crew would orbit the moon until their oxygen supplies run out. 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'?"[8] The engine, thankfully, worked perfectly, the crew came home safe, and the mission was a huge technological and national prestige success.[*]

Apollo 13 – The Lifesaving Power of Two

Subsequent crewed exploration missions to the moon departed Earth with two spaceships (i.e., the Apollo CSM and the lunar module). While the two spacecraft provided different functions, Apollo 13 demonstrated the benefit of having two ships capable of sustaining the crew. After an oxygen tank in the service module exploded, causing the electricity-generating fuel cells to fail when they ran out of oxygen, the crew was able to transfer from the command module to the lunar module. They powered down the command module to conserve its battery power for Earth entry. The crew used the descent engine on the lunar module for course corrections. Use of the service module's engine was felt to be too risky due to its proximity to the explosion. The crew endured nearly four days in cis-lunar space, looping around the moon before their return orbit brought them back to Earth. As they approached Earth entry, they transferred back to the command module,[†] jettisoned the lunar module and service module, and were able to make a safe splashdown on April 18, 1970, as 40 million Americans watched on live TV. Millions more watched from abroad.[9]

NASA's initial plans for return to the moon as developed by the Constellation program, which was active from 2006 through 2010, were similar to the Apollo concept of operations. An Orion capsule and a lunar lander named Altair would join in Earth orbit, and then an Earth departure stage would propel them both to the moon. Like Apollo, the Constellation astronauts would have a self-rescue capability if an Orion service module had a failure.

NASA's Artemis program, announced in 2019, employs a single ship concept for crew transport to and from lunar orbit. Artemis II is planned to perform a flyby of the moon using a free-return trajectory, with only the Orion capsule and its European Service Module. Artemis III, which will put astronauts on the moon, will also transit between Earth and lunar orbit with a single spacecraft. Consequently, the crew will have limited capability to save themselves in the event of an emergency. The present concept of operations is for the Orion to dock with a lunar lander or Gateway that is waiting for it in lunar orbit. A stricken Orion might be able to dock with the lunar lander or Gateway so that the crew could transfer from one craft to the other. Then the crew would have to wait for a rescue in lunar orbit. The time required to rescue the stranded crew would need to be within the duration of time that the lunar lander or Gateway can keep the crew alive.

The dearMoon mission taking private citizens around the moon in a SpaceX Starship will, as it stands today, also be a single ship mission. Assuming it launches in 2023, it will not have a contingency option of docking with NASA's lunar Gateway in lunar orbit in the event of an emergency, since the Gateway is not planned for launch until 2024.

Submarine Rescue

"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

[*] A few days after the mission, two engineers with Bellcomm determined that the crew's maximum survival was on the order of two to three weeks, depending upon the crew's ability to conserve resources. The study was purely academic as there was no capability to initiate a rescue even if the crew managed to survive for three weeks.

[†] The lunar module could not have saved the Apollo 13 crew if the explosion had damaged the command module's heat shield or otherwise rendered the command module inoperative. The lunar module was not designed to withstand Earth entry heating.

the submarine and prevents it returning to the surface?"[10] 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.[11] 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.

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. He 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.[12]

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.[13]

Momsem pioneered the development of a breathing apparatus subsequently called the Momsen Lung that would allow individual submariners to escape from a sunken sub. He also led and participated in efforts to improve deep sea diving capabilities. And most fortuitously, he 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.[14] 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."[15] Figure 1 shows an artist concept of the rescue chamber used to save the crew of Squalus.

The U.S. Navy replaced the rescue chamber in 1977 with a more capable Deep Submergence Rescue Vehicle (DSRV). The DSRV is a mini submarine that is attached to the back of another sub and then transported down to the sunken submarine. The DSRV then shuttles between the two submarines, bringing the crew from the disabled sub back to the rescue sub. The DSRV can be made available worldwide quickly, since it is transportable by the Air Force's giant C-5. This concept of operations may be instructive for space rescue (e.g., having a

Figure 1: Artist John Groth's concept of a rescue chamber used to save the Squalus crew.
(Image credit: United States Navy[16])

docking adapter or space rescue capsule that can be flown aboard a C-5 or C-17 to any launch site in the world).

Risk remains for submariners and some dire scenarios, such as sinking below crush depth, offer few rescue opportunities.[‡] Likewise, not all space mishaps will lend themselves to escape or rescue options. However, that seems weak justification for lacking space escape and rescue capabilities today.

Submarine rescue has more recently moved towards an international model. On August 12, 2000, the Russian submarine Kursk sank in 354 feet of water in the Barents Sea. Most of the crew were killed by the explosion and subsequent flooding of the sub, but 23 of the 118 crewmembers were alive in the aft compartment. Britain and Norway offered assistance that was initially declined, and help subsequently came too late. Norwegian and Russian rescue divers reached the submarine on August 21, but the remaining crew were found dead. The International Submarine Escape and Rescue Liaison Office was subsequently established by NATO in 2003 to support all nations with the humanitarian objective of saving lives at sea.[17]

‡ The crew of USS Thresher was lost on April 10, 1963 when the submarine sank below crush depth and came to rest in 8,500 feet of water. The USS Scorpion went missing in the Atlantic in May of 1968. The sub was found five months later in 10,000 feet of water.

Treaties

The Outer Space Treaty[§] entered into force in 1967. Article V alludes to the 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 Agreement of 1968.[**] However, 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.

Rescue and Escape Studies

The study of in-space rescue and escape dates back to at least 1959, when crew lifeboats were conceptualized. Over 30 space escape and space rescue studies between 1959 and 2000 are documented by Astronautix.[18] Over that period of time and through the end of the space shuttle era, there were other notable studies and rescue scenarios as described below.

In 1967, the 90th U.S. Congress published the results of a detailed study/survey of space flight emergencies and space flight safety. Their overview and recommendations (see Appendix A) seem quite appropriate for today. For example, they concluded 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." The congressional committee's recommendations included: having NASA and the Air Force work together to ensure that space flight be as safe as possible; that equipment be compatible to facilitate space flight emergency assistance techniques; and that the overall space safety effort of the government be carried out on a coordinated basis.

Two publications in 2009 which provide a comprehensive look at the topic of safety of human spaceflight systems space rescue are *Space Rescue: Ensuring the Safety of Manned Spaceflight* and *Safety Design for Space Systems*. These books draw much of their material from the Apollo program and subsequent U.S. human spaceflight programs.

Post-Apollo Spaceflight Programs

As the Apollo lunar missions were being conducted, NASA began making plans for follow-on programs, including Skylab and the space shuttle. Consideration was given to having space rescue capabilities for these new programs.

Space Shuttle Development

President Nixon approved the development of the space shuttle in 1972. The concept of one space shuttle rescuing another shuttle was initially a requirement but was later waived.[19] NASA did develop a prototype Personal Rescue Enclosure or "rescue ball" that could contain an individual astronaut for up to one hour and allow the transfer from a disabled craft to a rescue ship via extravehicular activity (EVA) with a suited crewmember. The rescue balls, however, were never flown.[20]

Skylab

There were three crewed missions to Skylab during 1973 and 1974. Apollo CSMs were used to ferry

[§] Formally called the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.

[**] Formally called the Agreement on the Rescue of Astronauts, the Return of Astronauts and The Return of Objects Launched into Outer Space.

crews to and from the Earth-orbiting station. NASA set up a rescue plan for each of the crewed missions in the event that a CSM were to be incapable of safely bringing the crew home. As there were three Skylab crewed missions (Skylab 2, 3, and 4), the next Skylab mission vehicle in line would serve as the rescue vehicle (i.e., Skylab 3 would be the rescue mission for Skylab 2, and Skylab 4 would be the rescue mission for Skylab 3).[21] The rescue plan was actually initiated during the Skylab 3 mission in 1972, when on August 2 the on-orbit spacecraft's quad thruster failed. The rescue launch campaign went into full swing for a week but was waived off on August 10 when it became clear that the on-orbit spacecraft could bring her crew safely home.[22]

The rescue plan was augmented for the final Skylab mission, Skylab 4, by having a Saturn 1B outfitted with an Apollo spacecraft configured to support a rescue. That rocket was positioned on the launch pad on December 5 and remained there until the Skylab 4 crew returned to Earth. The rescue rocket was returned to the Vehicle Assembly building, where it would wait to be used for the Apollo-Soyuz Test Project—a space rendezvous with the Soviet Union. [23]

Apollo-Soyuz Test Project

The Apollo-Soyuz Test Project, between two adversarial nations, came about as a part of the era of détente when President Nixon and Soviet Premier Alexei Kosygin signed an agreement in May of 1972.

There is a legend at NASA's Johnson Space Center that Martin Caidin's 1964 novel, *Marooned*, influenced the Soviet's decision to agree to the Apollo-Soyuz mission proposal.[24] In the original 1964 novel, a lone U.S. astronaut is stranded in orbit after his spacecraft's engines failed to fire for reentry and his oxygen supply is running low. NASA attempts to mount a rescue mission while the Soviets secretly prepare to come to the American's aid as well. Both rescue missions are launched, with the Soviet's rescue ship providing assistance for the American ship to complete the rescue. All the astronauts and cosmonauts return safely to Earth. In the 1969 film titled *Marooned,* and based on the 1964 book, there are three astronauts in an Apollo capsule that has debarked from an orbiting space station with the main engine again not being able to provide the reentry burn.

The mission would see the Apollo and Soyuz spacecraft dock in space so that the crewmembers could visit each other's ships and shake hands in orbit. The launch of the Apollo CSM included a docking adapter that was stationed in the rocket where the lunar module had been housed for moon missions. After launch the crew maneuvered the CSM and docked to the docking adapter. They then rendezvoused with the Soyuz and docked using the adapter.

The Apollo-Soyuz mission success provides a useful analog for considering future space rescue capabilities. It especially points to the need to develop and have available docking adapters.

International Space Station EVAs

Assembly and maintenance of the International Space Station (ISS) has required many extravehicular activities (EVAs), specifically spacewalks. The potential that an astronaut might drift off into free space away from the ISS was a concern to the spacewalkers. A device called a Simplified Aid for EVA Rescue (SAFER) was proposed that would allow an adrift astronaut to self-propel back to the ISS. The proposal was initially turned down until astronaut Jerry Ross asked space shuttle program manager Brewster Shaw, "What are you going to tell an astronaut's spouse when said astronaut is drifting off with their oxygen running low and their battery failing?"[25] Development of SAFER was approved. "We had to jog their conscience and help them make the right decision," said Ross.[26]

Columbia

On January 16, 2003, the space shuttle Columbia was launched on a life science mission carrying the SPACEHAB double research module in its cargo bay. During ascent, a large section of foam detached from the External Tank and struck the Orbiter's wing. NASA managers were made aware of the foam strike, but discounted the potential for foam to have done serious damage to the Orbiter's thermal protection system and in particular the wing leading edge reinforced carbon-carbon panels. However, damage had occurred. Columbia was destroyed, and her crew perished during reentry at the end of the mission on February 1, 2003. The report of the Columbia Accident Investigation Board concluded that if NASA had recognized the damage at the beginning of the mission, then a rescue by using the next space shuttle due for launch, Atlantis, would have been feasible. The rescue would have entailed maneuvering Atlantis next to Columbia and then transferring the crewmembers via individual spacewalks. "This rescue was considered challenging but feasible."[27]

Post-Columbia Space Shuttle Era

After the loss of Columbia and her crew in 2003, NASA required that every shuttle mission going to the ISS have a rescue plan in place prior to launch. The concern focused on potential damage during launch of the Orbiter's thermal protection system, similar to what had happened to Columbia, such that the Orbiter could not be counted on to safely bring her crew home. The primary considerations for the required rescue plan were how long could a crew survive while stranded at the ISS and how long would it take for the rescue shuttle to arrive. Missions to the ISS could proceed if there was reasonable confidence that another shuttle could arrive before the end of the survival duration estimate.

There was one mission that would not be going to the ISS: a servicing mission to the Hubble Space Telescope. NASA administrator Sean O'Keefe felt that the mission was too dangerous, since it would not have the ISS as a safe haven, and canceled the mission.[28] The next NASA administrator, Mike Griffin, reinstated the mission using the shuttle, but only after NASA took extra precautions, including the development of a credible rescue capability. The plan NASA came up with was to make use of both shuttle launch pads and have two shuttles ready for launch. The first would go to the Hubble while the other, configured for a rescue mission, would only launch if required. After the servicing mission was completed without a problem, the rescue shuttle was reconfigured for the next mission to the ISS.[29]

The concepts of operations for both Skylab and shuttle rescues made efficient use of assets that were already planned to be launched at some point. This greatly reduced the cost of having the rescue capability and is a potential model to be employed again in the future.

In hindsight, having a launch-on-need capability made good sense and was an important "lesson learned" from the Skylab and space shuttle programs. China appears to have taken heed for crewed Shenzhou spacecraft missions to 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."[30]

Such lessons, however, do not appear to have endured at NASA or the U.S. commercial spaceflight providers. There are no rescue plans in place when crewed spacecraft are being launched. There are no standby launchers as there were during Skylab or the final shuttle mission to Hubble.

Imagine the public outcry that could arise if an Inspiration4, Axiom, dearMoon or a similar mission were stranded in LEO or cislunar space by a disabled spacecraft. The underlying problem could be any number of issues, such as damage to the heat shield from an orbital debris strike, failure of the solar arrays, failure of the spacecraft's avionics, or failure of the propulsion system. The spacecraft may only be able to sustain the crew for a week or two at most. Unless plans are put in place ahead of time, there would likely be no way to save the crew. Much like the Navy, as their surface ships listened in vain to the hammer taps of the dying crew of the S-4 submarine lying just 140 feet below the surface, the entire world would be able to hear from the doomed crew until they eventually succumbed to a fouled atmosphere. This does not have to be an accepted risk.

International Docking System Standard

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 International Docking Standard was derived in part from the docking adapter used during the Apollo-Soyuz test project. 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."[31]

NASA's implementation of the International Docking Standard is called the NASA Docking System. Boeing designed and built a NASA Docking System for their CST-100 Starliner.[32] The Orion spacecraft being built by Lockheed Martin will also use a NASA Docking System.[33] SpaceX developed their own unique docking system for Crew Dragon.[34] While all these spacecraft should theoretically be able to dock with one another, there is some debate as to whether or not the docking systems currently being implemented are fully androgynous.[35]

Capability Options

The development of space rescue capabilities needs to be based, at least in part, upon the spacecraft being launched. An assessment should be performed such that it is known ahead of time how long crew can survive in space if there is an anomaly. That can then be used to determine the response time required and inform the design of the rescue systems that would support a rescue effort.

If time is so short that rescue is not a viable option, then self-rescue options, such as having a lifeboat capability are desirable. This option has effectively been employed for the ISS. The size of the crew on the ISS is limited so that in the event of an emergency, such as a fire or depressurization of the station, all crew members can escape using the currently docked spacecraft at the station.

Constraining the number of crew members on the ISS, however, also limits the amount of science that can be performed. Consequently, NASA made several attempts to develop a dedicated lifeboat that could be attached to the station and allow for the number of astronauts on the ISS to be increased. After the loss of Challenger, NASA baselined the Assured Crew Return Vehicle (ACRV). The ACRV would be used:

1. To return an ill or injured astronaut to Earth;

2. To return the entire crew to Earth in the event of a catastrophic failure on Freedom; or

3. To return the crew to Earth if the space shuttle was unavailable.

There were 12 different attempts to define an ACRV configuration, but none became operational. The X-38/CRV space test article was 75 percent complete when the project was cancelled. That project was a substantive attempt to create a spacecraft dedicated to rescue or escape. The lessons learned from that program would likely be a good starting point for any future attempts to develop a space lifeboat or space rescue craft.[36]

The commercial crew vehicles, Crewed Dragon and Boeing CST-100 Starliner, are designed to stay at the ISS for up to 210 days. During their extended stay period, they will act as lifeboats for the ISS as depicted in Figure 2.

If the time is very short, but not so short that there is no hope of rescue, then having pre-deployed capabilities in space may be one option. An apt

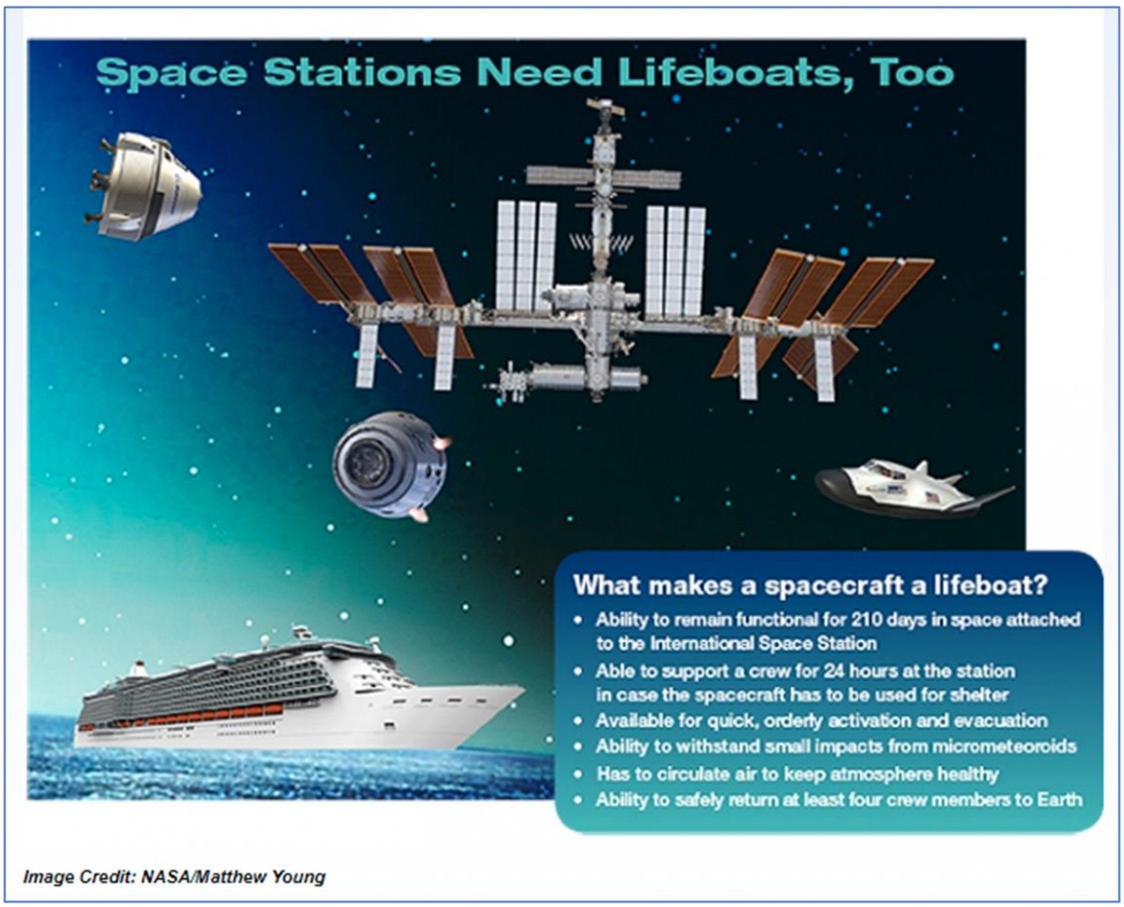

Figure 2: Space stations need lifeboats, too. *(Image Credit: NASA[37])*

analog is Navy carrier flight operations called "Plane Guard." When an aircraft carrier is performing air operations (i.e., launching and landing aircraft), either a rescue helicopter is flying nearby or a ship is keeping station near the carrier in case an aircraft crashes into the ocean during landing or takeoff. The rescue helicopter or ship can then be at the crash site in minutes to rescue the pilot(s). In similar fashion, a rescue spaceship could be pre-deployed in an orbit that would allow rapid rendezvous and dock. Such a craft might even be docked at the ISS or any other orbiting station such that astronauts already in space could be called upon to make a rescue attempt. A robotic rescue vehicle with the capability to orbit for long periods of time might be an option for having a timely capability. The design of future extended duration crewed missions to the moon or to Mars may need to consider the benefits of traveling with multiple ships such that one ship could rescue the crew of the other in the case of an emergency.

If days are available to initiate a rescue, then launch-on-need capability becomes a viable strategy. Launch-on-need requires an available rocket, rescue vehicle, launch complex, and personnel to conduct a launch campaign successfully within a matter of days from call-up. NASA demonstrated during the Skylab and shuttle programs that such a capability can make use of existing assets to minimize costs.

Orbital launches are occurring with increasing frequency worldwide. Fiscal year 2021 is on pace to see over 120 launches. This means that at any time during the year, there is on average a rocket within approximately three days of launch. Having an ability to integrate a rescue spacecraft with the next available rocket could provide a modest rescue capability for distressed spacecraft in Earth orbit.

To enable rescue, there needs to be physical compatibility to allow a rescue vehicle to safely dock with a spacecraft needing rescue. This points to the need to have all crewed spacecraft make use of docking systems that are fully compliant with the International Docking System Standard.

Missions for which there is no capability for rescue or escape should perhaps consider how to tailor the mission to improve safety. For example, a near-term option for a mission such as Inspiration4, which is not planned to go to the ISS, would be to launch into an orbit in close proximity to the station such that in the event of an emergency, the Inspiration4 crew could have a viable option of docking with the station. However, the current plan for the Inspiration4 Dragon spacecraft is to remove the ISS docking port and replace it with a viewing port.[38] The removal of the docking port nullifies any potential for rescue.

Benefits and Synergies

The principal benefit of space rescue is that it reduces the likelihood of dying in space. However, having space rescue capabilities will likely provide other important benefits. For example, as perceived risks are reduced, more people may be willing and able to travel in space.

> Lowering the cost of access to space and sound competition are necessary factors for commercialization, but only safer and sustainable space operations can allow commercial space to fully develop and prosper.[39]

It has also been suggested that a rescue capability, if it can be counted on ahead of time, allows the reliability of a spacecraft to be reduced. And because costs can be very high to achieve extremely high levels of reliability, especially as flight times increase, having that rescue capability may lower the cost of spacecraft.[40]

Space rescue will likely be synergistic with other enablers required to fully exploit the space domain. Systems that enable rescue will likely have similarities to commercial space servicing capabilities, such as those being demonstrated by Northrop Grumman's Mission Extension Vehicle that has recently docked with an Intelsat spacecraft.[41] A universal docking adapter is analogous to universal modular interfaces that enable interoperability between orbiting assets, be they crewed or otherwise. Such modularity is expected to be a critical enabler to the on-orbit assembly capabilities required for increasingly complex space missions.[42] Perhaps most importantly, if launch-on-need can be put in place for space rescue, then it can also be available for the responsive launch needs of the nation, including replacing the unexpected loss of on-orbit capabilities and providing new capabilities in space to support national security in times of crisis.

Potential Charters for Action

Who should be responsible for space rescue? Should it be the entity that launches the crew or should there be a centralized space rescue capability that would be available to all? Table 1 provides an overview of potential rescue models.

Assuming that a government entity should have a space rescue mission, there seem to be two logical candidates: NASA and the United States Space Force. 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.

On the other hand, the Space Force is responsible today for rescuing NASA and commercial 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 could be synergistic with Space Force's desire to have responsive space capabilities to enable replacement of failed satellites in orbit, reconstituting space capabilities taken out by an adversary, or rapidly putting in place capabilities

<table>
<tr><th colspan="3">Table 1: Potential Rescue Models, Key Elements and Common Needs</th></tr>
<tr><th>Rescue Model</th><th>Key Elements</th><th>Common Needs</th></tr>
<tr><td>Government organization (e.g., Space Force and/or NASA)</td><td>Rescue charter is integrated into existing government organization and funded. Space rescue capabilities are operated and managed by chartered government organization.</td><td rowspan="4">Universal docking adapters

Responsive launch

Spacecraft that lend themselves to being rescuable

Spacesuits that enable escape from a disabled spacecraft[††]</td></tr>
<tr><td>New government organization</td><td>Grows over time as need for services grow.</td></tr>
<tr><td>Regulatory-driven commercial model</td><td>Compliance standards and enforcement.</td></tr>
<tr><td>International consortium</td><td>Shared funding, resources, and responsibility.</td></tr>
</table>

[††] Spacesuits would not be needed for rescues in which a rescue spacecraft docks with a disabled spacecraft.

required to respond to a national emergency or emerging international threat. Indeed, 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. If not one or the other, then potentially both could be chartered to work together to develop and maintain a space rescue capability. This seems to have been the approach suggested by the 1967 Congress (see Appendix).

Suggestions have also been made that the United States could create a "Space Guard" analogous to the Coast Guard.[43,44]

> **Search, rescue, and recovery operations in space**. Again following the Coast Guard model, a USSG would be the logical agency to make responsible for search, rescue, and recovery operations. To date, there have been no active space-rescue missions; rescue operations have been more a matter of backup and contingency plans. But as the level of activity in space increases, permanent rescue capabilities, and staff dedicated to such functions, will probably become a necessary part of the national space establishment.[45]

One alternative to having a centralized government space rescue capability would be to make the entity launching a crew into space responsible for its rescue in space. Since commercial crewed launches are licensed by the FAA, such a policy would necessitate the FAA making rules and regulations to enforce a space rescue requirement. If such a policy were to be in place today, for example, SpaceX and Boeing would not be allowed to launch people into space unless they could demonstrate to the FAA that a rescue, if needed, could be performed either by launching a rescue mission, having a lifeboat on the spaceship ready to deploy, or having some other type of capability in space that could provide a rescue. This would be analogous to the NASA administrator not allowing the HST servicing mission to be launched until he was shown that a viable rescue option existed.

Industry might initially balk at a government-mandated crew rescue requirement. Or would they? Some companies might see substantial value and opportunity. A startup space company, Silver Shield Industries (Kirkland, Washington), is developing their *Sparrow* spacecraft for use as a rapid deployment crew rescue vehicle.[46] A paper describing design concepts for orbiting microhabitats as space lifeboats is planned to be published later this year.[47] Given the prodigious abilities demonstrated by SpaceX, developing space rescue might not be so insurmountable and might be of interest to SpaceX founder Elon Musk. When 12 Thai boys and their soccer coach were trapped in a cave by rising waters, he quickly marshalled the forces of his three companies—SpaceX, Tesla, and the Boring Company—to develop and deliver a rescue pod. Though it was not used, it demonstrated Musk's resolve to offer rescue services to those in need.[48] Having such a space rescue capability for its own spacecraft, SpaceX might then offer that capability to others, such as for Boeing's CST-100. Boeing could contract with SpaceX to meet a requirement for space rescue or, alternatively, Boeing could develop its own capability, perhaps by leveraging the know-how developed from of the X-37B autonomous spaceplane. Likewise, Sierra Nevada has aspirations for its Dream Chaser spaceplane that could be extended to space rescue. Ideally, having a common capability to dock spacecraft with each other would enable whichever spacecraft is next to be launched to serve as the rescue mission, if required.

Another avenue to consider is an international consortium approach, such that all spacefaring nations pool their collective resources to develop and maintain rescue capabilities. This tactic could be taken in parallel with any of the approaches suggested above. It has been suggested that the "Space Guard" could be an international organization.[49]

Conclusions

The United States has no present capability or policy for conducting in-space rescues. This despite:

- Having studied space escape and rescue systems since 1959.
- Having demonstrated a self-rescue capability during Apollo 13.
- Having put in place rescue capabilities for the Skylab mission.
- Experiencing the hard-learned revelation of the importance of in-space rescue options after the loss of Columbia and her crew.

A space rescue capability is likely to be highly synergistic with the long-sought-after capability of having responsive launch capability. Perhaps a good first step to achieve both would be for the U.S. Congress to establish a policy such as: "It should be the policy of the United States to develop and put in place rapid launch-on-need capability to support: timely rescue of astronauts in cis-lunar space; rapid reconstitution of nationally important space assets; and the ability to put in place new space capabilities in response to emerging threats in near real time."

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. The only question is if they will be developed before or after the next crisis that requires that capability.

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APPENDIX A

1967 Congressional Survey of Space Flight Emergencies and Space Flight Safety[50]

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.

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.

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.

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