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Short Communication

A roadmap to astronauts' water survival training and strategic rescue post splashdown

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ABSTRACT

Planet Earth offers two elements on which a spacecraft can carry out landing – land (touchdown) and water (splashdown). This means that the recovery techniques would have to be divided, and therefore, training to survive both on different terrain conditions and in water would also have to be imparted to the astronauts. Where the Russian Cosmonauts traditionally have been carrying out touchdown with their Soyuz MS space vehicle on the terrains of the Kazakhstan border, the American counterparts have resumed splashdown re-entry with the latest partially reusable SpaceX Dragon Crew Capsule. Astronauts' water survival training has been a major component of mission preparation. It encompasses both nominal and off-nominal situations that the crew may encounter during their return. This paper highlights various past and present water survival and crew rescue training procedures followed by international space agencies and also attempts to come up with recommendations for water survival training and rescue plans for Indian astronauts-to-be in preparation for the Gaganyaan Mission.

Keywords: Astronaut, Splashdown, Water survival training, Crew rescue

INTRODUCTION

Training of astronauts for survival and rescue encompasses knowledge, demonstration, and hands-on practice on spacecraft and survival systems, including training on their failure modes and redundancy modes, both in nominal and off-nominal conditions. Simulation of survival and crew egress procedures is practiced repeatedly alongside training of re-entry procedures during the mission preparation phase to ensure that the crew members are skilled in anticipating potential real-time dangers during their return to Earth and are taking all possible corrective measures for survival. The astronauts need to be trained on both land and water survival techniques. Water survival training has been an integral element of spaceflight preparation since the inception of the National Aeronautics and Space Administration astronaut program.[1]

The initial suborbital flights under the Mercury Program were recovered from the Atlantic Ocean, and that initiated a trend for US astronauts to carry out splashdown on the Atlantic or the Pacific Ocean during all Mercury-Gemini, Apollo/Skylab/Advanced Space Transportation Program missions between 1961 and 1975.[2] Thereafter, since 1981, all astronauts and cosmonauts have intended to land on soil. Now, with the latest SpaceX Dragon crew capsule recovery, strategic water landing and crew evacuation have again gained importance.[3]

The final choice of water or land depends on the country's geography and the structural limitations of the spacecraft. Russia, historically, had minimum aircraft carriers. A sturdy Soyuz capsule with a

large territory in the borders of Kazakhstan without too many man-made landing hazards made it easier for them to choose touchdown. However, the Soyuz does have the capability to land into water in off-nominal scenarios.[4] Landing on soil needs the utilization of terminal braking solid rockets and engines to reduce the impact velocity. Whereas, splashdown is possible even at interplanetary re-entry speeds, partially due to water compressibility.[5] Hence, most of the modern spacecraft, such as SpaceX Dragon and the prototype Orion module, could cut down on mass budget by doing away with the bulky and heavy engines required for terminal braking and, hence, adopt water landing as their re-entry procedure of choice.

This paper attempts to highlight some of the historical water egress and survival training for astronauts conducted by international space agencies and, draw parallels from the internationally conducted water survival and rescue training procedures, and come out with recommendations to formulate a tailor-made training protocol for Indian astronauts-to-be, keeping in mind the subcontinental sea conditions.

WATER SURVIVAL AND RESCUE TRAINING OF THE PAST AND PRESENT

The American way

Mercury

The astronauts of the Mercury program were trained in landing on the water, spacecraft egress, and helicopter recovery. The direction of the launch and the orbital path were aimed away from the large habitable areas with recovery in the Atlantic Ocean. For Mercury 7 (the first 07 American astronauts), water survival training was initially conducted as a group. It was then followed by individual refresher courses on flight assignments. The course included revised egress and recovery procedures and exercises. They also completed a scuba-diving course. A series of lectures and training videos were shown before they practiced simulated survival operations in a tank and then in open water after a month. The total duration of this egress and water survival training was 25 hours. The egress training was divided into 03 phases:-[6]

(a) Phase-I egress training. The astronauts practiced exits, both when suited with pressure garments and without suits, from the top hatch of a spacecraft module (scaled 1:1). These exit drills were performed first in calm water and then in simulated waves up to 0.6 m high.
(b) Phase-II egress training. During this 02-day training phase, the astronauts were trained at a Naval Air Station where they practiced egress in the open waters of the Gulf of Mexico. The astronauts were trained to egress from both top and side hatches.
(c) Phase-III egress training. In this phase, a series of underwater egress exercises was carried out from a submerged spacecraft with the astronauts wearing pressure garments.

Gemini

The 02-crew Gemini program also featured a water landing. The training included scuba diving, water recovery drills and wilderness training like in the Mercury program.[7] In addition, the astronauts were trained in jungle survival and water parachute training with parasailing as part of their survival training. Egress training in water was conducted for 13 hours per astronaut. It included lectures and mock-ups floating in a tank and in open water. They also practiced exiting the spacecraft from the surface as well as underwater.

Apollo

One historical space exploration was Apollo 11, which marked the first successful moon landing in 1969. The crew successfully achieved the moon landing. However, not many know the story during their water recovery post-landing. One such incident occurred during the Apollo 11 mission. After the historic moonwalk, astronauts Neil Armstrong, Buzz Aldrin, and Michael Collins returned to Earth. The command module, carrying Armstrong, Aldrin, and the precious lunar samples, splashed down in the Pacific Ocean on July 24, 1969. However, the module capsized due to rough seas, posing a potential threat to the astronauts' safety. Swift action by recovery teams, including helicopters and Navy ships, ensured the prompt rescue of the Apollo 11 astronauts.

The re-entry and splashdown of the Apollo 13 capsule also presented its challenges. The spacecraft's trajectory had to be carefully calculated to ensure that it would hit a specific target area in the Pacific Ocean, where recovery teams were stationed. Despite the tense moments during re-entry, the capsule successfully splashed down, and the crew quickly recovered.

Water survival and egress simulations from the ocean were integral parts of the Apollo training program for astronauts.[8] This was incorporated into the overall survival training for astronauts, which also included tropical jungle and desert training. Egress training was undertaken first in the form of didactic classroom lectures, followed by simulations using an engineering mock-up of the Apollo Command Module. Initially, these procedures were completed in a water tank before it moved to the Gulf of Mexico where the crew practiced exiting the spacecraft from the surface in the "Apex-up" position and then underwater egress in the "Apex-down" position. The final training was fully suited.

Skylab

On similar lines to Apollo water survival training, crew members of Skylab undertook water survival and egress

training on a modified five-person crew training module with scenarios simulated Skylab rescue mission.[9]

Shuttle

The era of the Space Shuttle saw considerable change in astronauts' survival and emergency training as the US achieved more control of where the spacecraft would land. The training saw further modifications when the astronauts started training on basic International Space Station (ISS) systems. The training now included swimming and scuba qualification and water survival post abandonment of a T-38 aircraft.[10] In addition, it included jumping from a tower while wearing tethered parachute harnesses as they slid down a wire to a water landing. The astronauts were also towed through water in a parachute harness simulating a scenario where they had to release themselves off the harness that was being dragged across the water surface. They also had to undergo parasail towing with sudden release to land in the water. The final stages of the training would be with full survival gear, followed by a rescue operation by a helicopter.

SpaceX dragon

Unlike the contemporary market counterparts like Starliner, SpaceX incorporated touchdown in water, and hence, the ISS astronauts now undergo water survival training in the Neutral Buoyancy Laboratory at the Johnson Space Center. However, the laboratory is built to simulate weightless conditions during space walks and is not properly equipped to simulate water surface conditions for recovery training. Therefore, additionally, in the USAF Survival School, the astronauts are put through the paces of bailing out from a simulated crash landing in water.[11] They learn to deploy and secure a life raft, rescue endangered crewmembers, avoid hostile forces, and experience being hoisted into a rescue vehicle.

The Russian counterpart

Vostok

In preparation for their Vostok mission, the cosmonauts had to undergo water survival training due to the possibility of splashdown in an off-nominal landing. Hence, they practiced survival skills with full egress equipment in the Black Sea.[12] Simulated parachute drag drills were also carried out by towing the cosmonauts on their backs and dragging them in a water tank.

Zond and Buran

Zond was designed in similar lines to Soyuz and was being prepared for manned lunar missions. It included ocean landing as an option, and hence, the cosmonauts were trained in sea survival skills. However, the project was canceled, and there is scarce literature on the overview of their cosmonauts' mission preparation.

The Buran, like the US Space Shuttle, included ejection seats, and hence, there was the possibility of ejection in the rugged mountains of Northern Asia. The water survival training was not dissimilar to the Soyuz water survival training.[13]

Soyuz

Since 1967, the only fully operational Soviet manned spacecraft has been the Soyuz. This spacecraft has undergone updates and modifications through the years and obtained enhanced capabilities; however, its basic flight profile remained more or less unchanged. Soyuz was also targeted for terrain landing. However, it is capable of splashdown re-entry, and therefore, all crew members train for water recovery. The Soyuz 23 unfortunately had to endure bad weather conditions during return which culminated into landing in Lake Tengiz of Kazakhstan in the night.[14]

The water survival training would be initially in a hydro-tank before the cosmonauts get trained in open water. They would be dropped in the sea while being inside a mock-up Soyuz capsule in their *Forel* survival suits and carrying a *Neva-KV* floatation device.[15] They were trained to exit the spacecraft, jump into an inflatable dinghy, and be slung by a helicopter. They would also be trained to sustain themselves either inside a closed capsule or on the dinghy for a long duration which added the physiological stressors of heat exhaustion and sea sickness.

The Chinese program

The *Shenzhou* is similar to the Russian Soyuz Spacecraft. However, there is little available open literature about their taikonauts' survival training. Photographic evidence suggests that the water egress and rescue training would be similar to what other space-faring nations follow.

INDIAN ASTRONAUTS' WATER SURVIVAL AND RESCUE TRAINING – CONCEPTUAL STANDPOINT

India's maiden indigenous Human Spaceflight Program – Gaganyaan, is intended to perform a re-entry splashdown of the Orbital Module in either the Bay of Bengal or the Arabian Sea.[15] Therefore, it is imperative that the astronauts get trained and refresh their sea survival and rescue skills. In addition, the crew module must include emergency survival equipment and supplies that provide a reasonable chance of survival for all occupants in post-landing emergencies. The paper aims to draw parallels from the internationally conducted water survival and rescue training procedures and come out with recommendations to formulate a tailor-made

training protocol for Indian astronauts-to-be, keeping in mind the subcontinental sea conditions.

Physiological effects of the sea

The sea, or the ocean, can have various physiological effects on individuals, both short-term and long-term. Here are some key physiological effects:

Hydration and dehydration

Being surrounded by saltwater, individuals may experience increased humidity, which can affect the body's hydration levels. The high salt content of seawater can draw moisture from the skin, leading to dehydration if not properly managed. Conversely, exposure to the sun, wind, and saltwater can contribute to dehydration, as the body loses fluids through sweating and increased respiratory evaporation.

Electrolyte imbalance

Prolonged exposure to seawater can lead to an imbalance in electrolytes, particularly sodium. Ingesting seawater can exacerbate this imbalance, as the high salt content can disrupt the body's normal sodium levels, leading to dehydration.

Thermal regulation

The sea can influence body temperature regulation. Immersion in cold water can cause hypothermia, while exposure to direct sunlight and warm water can lead to overheating and heat-related illnesses.

Skin moisture

Exposure to seawater can have both positive and negative effects on the skin. While the minerals in seawater can have a moisturizing effect, prolonged exposure without proper hydration can lead to dry and irritated skin. Saltwater can also have a corrosive effect on certain materials, affecting skin health indirectly.

General considerations of the sea

The impact of a touchdown in the sea has different contemplations than that in a freshwater body. Sea poses extra challenges to the survival of an individual. The following considerations are to be kept in mind while developing the training protocol:-

Re-entry motion sickness and sea sickness

The astronauts, after space dwellings, have deranged cardiovascular and neuro vestibular systems. This manifests as Re-entry Motion Sickness and is a significant hazard in the initial few hours after landing. Similarly, constant sea waves would cause sea sickness. This motion sickness is more prevalent when being inside the crew module. Being in the sea inside a hydrosuit would not cause motion sickness. However, it would again be caused while being inside a dinghy/raft.

Sea spray aerosol (SSA)

The nose of an astronaut while being afloat in a hydrosuit is positioned right at the junction of the air-sea interface where there exists SSA. This reduces to a certain extent while sitting inside a raft/dinghy, especially if the dinghy is covered. Even without the water entering the nostrils, the presence of the salt aerosol at the air-sea interface gives a constant uncomfortable feeling of inflammation. When seawater gets into the nostrils, this inflammation gets stronger and is uncomfortable. Breathing in salt particles can also contribute to coughing and discomfort.

Organic matter bubbles

This is also a part of sea spray and gives an uncomfortable feeling in the beginning immediately upon entering the sea. The odor may induce vomiting in a few individuals. Primarily, the odor is a strong smell of fish and sea creatures which may be disturbing to a few.

Salt water ingestion

Accidental ingestion of salt water to the extent that with only the seawater touching the tongue under water-deprived thirsty conditions of sea survival induces a significant level of thirst for a few minutes, which has to be suppressed. The physiological ill-effects of seawater ingestion exist with the development of hyponatremia and neuropathy in severe cases. The crew members need to be informed about the pathology.

Increased buoyancy

Floating in seawater can reduce the impact on joints, providing relief for individuals with certain musculoskeletal conditions. In addition, buoyancy can affect blood circulation by reducing the strain on the cardiovascular system. Furthermore, during swimming, there are two physical efforts required by a human being: one is to stay afloat at the surface, and the second is to propel himself/herself horizontally. Increased buoyancy inside the sea would be an advantage while swimming from one place to another. When leaving a raft, this aspect has to be borne in mind. Furthermore, while approaching the coastline from deeper sea waters, the sea currents, in effect, assist the survivor in taking them ashore.

Sea surface visibility

Visibility in sea conditions is poor compared to freshwater due to the sea-air elements discussed above. It may be difficult to visually trace a fellow crew member or locate a rescue ship in spite of them being only a few hundred meters away. The same is also the case while leaving a raft. That is also the reason why it is important to secure every man/equipment/dinghy with a lanyard/rope. Aural signals can be used like a whistle to locate a person who has gone adrift.

Hostile aquatic life

The marine aquatic life is known to be hazardous to humans. Usually, sea survival training is undertaken in waters that are known to be not shark-infested. However, that is an assumption, to say the least. It is only a mitigating factor else it would not be possible to undertake the training at all. Therefore, the presence of that underlying fear is a psychological factor. Training in the actual sea does build up the confidence of an individual and assures him a certain degree of mental satisfaction of having been in actual conditions.

Survival scenarios

The crew should be trained on all possible survival scenarios in the water. In this regard, the following two scenarios are probable in the Gaganyaan Mission and need crew training.

Life inside the closed orbital module

An intact crew module is supposed to float in the water with the base of the cone downward without any additional floatation aids. The crew would not need to abandon the module unless its integrity is breached or its interior rendered uninhabitable. It is expected that the space crew would remain in the safety of the crew module with the hatch closed. In such a case, the orbital module should have a functional life support system to support the crew in case of a closed-hatch survival scenario.

Life in case the module has to be abandoned

Conditions like loss of structural integrity of the module or an un-inhabitable module would render the crew to take egress actions and abandon the module and land up in the open sea. In such a case, the emergency survival kit (ESK) would be required by the crew. The contents of the ESK should be based on marine survival requirements as per standard operational practice in the Armed Forces.

Recovery plan

The astronaut candidates need to be familiarized and trained on the planned rescue operations, and available search and rescue (SAR) aids in their kitty.

Roadmap for Indian water survival and rescue training protocol

Based on the above deliberations, Indian astronaut candidates also need to undergo structured water survival and rescue training as part of their mission preparation. A typical training protocol roadmap is presented below:-

(a) Day 1: Familiarization and acquaintance with equipment. This may include
   (i) Initial briefing
   (ii) Practical demonstration of the crew module
   (iii) Demonstration of procedure of donning the survival suit (e.g., Forel suit of the Russians) and capsule egress
   (iv) Demonstration of use of contents of the ESK

(b) Day 2: Dry run. This may include the following in chronological order:-
   (i) The procedure of capsule ingress
   (ii) Procedures for food and water usage during survival
   (iii) The procedure of capsule egress
   (iv) The procedure of water ingress
   (v) Actions on entering the sea
   (vi) Use of ESK
   (vii) Extrication onto the rescue boat
   (viii) Wet winching onto the rescue helicopter
   (ix) Debrief
   (x) In addition, a safety briefing may be undertaken before the training to make the astronaut candidates aware of possible safety hazards during the training procedures.

(c) Day 3: Off-nominal egress and evacuation training.

The chronology of this training may be similar to the training of nominal egress, but it should cover all possible off-nominal aspects, like landing in locations where crew rescue would be delayed, landing with a decompressed crew module, and landing with a failed life support system and include actions to be taken during each such situation.

(d) Day 4: Practice drills of nominal and off-nominal evacuation procedures.

(e) Day 5: Night training. Even though the mission planning is such that the crew module impacts one of the points on the earth's surface where there is the ocean and which could be sunlit, the crew would be exposed to night operations while the search and rescue operations are on. Thus, this requires to be catered by ensuring adequate sea survival training by night including both inside and outside the module.

CONCLUSION

Astronauts have to be prepared for almost everything in space, but also anything on the ground. There could be an

emergency landing in a faraway place. Spacecraft may be forced to come down in the sea, desert, tropical rainforest, or on a glacier in summer or winter. The Indian Manned Spaceflight Program is intended to perform a touchdown of the capsule in the Indian waters. Before the astronauts can be rescued, they may have to rely only on very basic items and the emergency pack in their capsule. The water survival and rescue training, thus, becomes a crucial component of our mission success, and hence, it is considered to be a vital part of the basic training of our astronauts.

Ethical approval

The Institutional Review Board approval is not required.

Declaration of patient consent

Patient consent is not required as there are no patients in this study.

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Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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