POSTLANDING OPTIMUM DESIGNS FOR THE ASSURED CREW RETURN VEHICLE

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The optimized preliminary engineering design concepts for postlanding operations of a water-landing Assured Crew Return Vehicle (ACRV) during a medical rescue mission are presented. Two ACRVs will be permanently docked to Space Station *Freedom*, fulfilling NASA's commitment to Assured Crew Return Capability in the event of an accident or illness. The optimized configuration of the ACRV is based on an Apollo command module (ACM) derivative. The scenario assumes landing a sick or injured crewmember on water with the possibility of a delayed rescue. Design emphasis is placed on four major areas. First is the design of a mechanism that provides a safe and time-critical means of removing the sick or injured crewmember from the ACRV. Support to the assisting rescue personnel is also provided. Second is the design of a system that orients and stabilizes the craft after landing so as to cause no further injury or discomfort to the already ill or injured crewmember. Third is the design of a system that provides full medical support to a sick or injured crewmember aboard the ACRV from the time of separation from the space station to rescue by recovery forces. Last is the design of a system that provides for the comfort and safety of the entire crew after splashdown up to the point of rescue. The four systems are conceptually integrated into the ACRV.

INTRODUCTION

For years, America's journey into space has demonstrated the benefits associated with working in the unique environment of microgravity. Continuing in this tradition, humans will soon launch an ambitious and far-reaching program to further the advancement of space technology. With the advent of Space Station *Freedom*, the U.S. will enter an era marked by a permanent presence in space. Moreover, the space station will allow continuous rather than intermittent operations to be conducted in orbit. The space station will open doors to many new methods of research and experimentation. Furthermore, humans will have a better opportunity to observe the Earth and forecast future trends from a vantage point only partially exploited by previous shuttle missions.

Space Station *Freedom* will eventually be permanently manned by a crew of eight. The crew will be rotated and resupplied by flights of the orbiter on an interval currently planned for three months[1]. Due to the isolation and potentially hazardous conditions involved in space operations, NASA is committed to the policy of Assured Crew Return Capability for Space Station crews in the event: (1) a medical emergency occurs and an ill, injured, or deconditioned crewmember must be rapidly transported from the Space Station to a definitive health care facility on Earth; (2) a Space Station catastrophe forces a rapid evacuation of the crew from the station; or (3) the National Space Transportation System becomes unavailable, and an orderly evacuation of the crew from the Space Station becomes necessary. These events, or Design Reference Missions (DRMs), can be met by a concept known as the Assured Crew Return Vehicle (ACRV). Currently, NASA is considering three classes of ACRVs: water landers, runway landers, and open land, or nonrunway, landers.

The task objectives detailed in this report, will be limited to those required for a water-landing ACRV, medical and crew support subsystems, and postlanding operations. Some of the medical and crew support subsystem designs will also support in-flight operational requirements. All designs presented follow the performance requirements and operational constraints supplied in JSC-31017 "CERV Systems Performance and Requirements Document."

DESIGN CONSIDERATIONS

The ambulatory nature of returning an ill, injured, or deconditioned crewmember back to Earth aboard a water-landing ACRV requires new technologies and operational procedures. The possibility of further injury or illness would compromise the mission. Following are general design considerations associated with the Apollo-based ACRV from the point immediately after splashdown to rescue by recovery forces.

The first major concern is providing crew egress and rescue personnel support subsystems. These subsystems include an emergency egress couch (EEC), a mechanism for removing the couch safely, and the necessary hardware for the assisting rescue personnel.

The EEC plays a vital role in the medical portion of the ACRV mission. The EEC must insure the safety of the sick or injured crewmember throughout all phases of the return mission. The design provides for the immobilization of the injured crewmember in a fully supine position from the hips up. Provisions are made to incorporate the necessary equipment in the couch to sustain the injured crewmember throughout the mission. The design insures the sick or injured crewmember is protected from the sea environment during egress.

The mechanism required to safely and quickly remove the EEC is termed the Rapid Egress System (RES). It must insure the minimum trauma removal of the sick or injured crewmember from the ACRV without endangering the rest of the crew or rescue personnel. The RES is designed to include features that allow the couch and the injured crewmember to be safely transferred to a rescue vehicle. The design must provide the means for displacing the couch a safe distance from the ACRV.

The incorporation of a rescue personnel support (RPS) system is mandated by the necessity to provide for the safety of the rescue personnel and crewmembers. Strategic placement and accessible design of handholds, supports, and platforms used by the rescue personnel facilitates the successful manipulation of the craft and medical couch during recovery operations.

The second major concern is the proper orientation, attitude control, and stabilization systems required for the ACRV in the marine environment. Experience gained from previous Apollo water landings has shown that some sea and weather conditions cause severe discomfort to the crew. In the case of an injured crewman, this could cause further aggravation of an already existing injury, or even death. Instabilities of yaw, pitch, and roll motions of the ACRV also cause the attending crewmember to be ineffective. A more serious problem arises if the ACRV lands in an inverted position. Rescue is impossible if the craft remains in this orientation.

The objective of the ACRV orientation system is to ensure an upright postlanding orientation. ACRV vehicles may have multiple stable positions, with only one being the preferred. The Apollo craft had both Stable-1 (upright) and Stable-2 (inverted) positions during its postlanding mission phase. The Apollo landed approximately 50% of the time in the Stable-1 (preferred) position and, therefore, required a change of orientation nearly 50% of the time.

The attitude system is more than an extension of the orientation system. It provides an assisting buoyant force to counter the weight of the ACRV, which is approximately 10,000 lb. The system raises and maintains the ACRV high enough above the water to allow safe crew egress and rescue support. The planform area of the craft (the total area as seen from above) increases as it assumes the postlanding position. This increases the moment required, through wave action, to tip the ACRV over to an undesirable position. The attitude system also furnishes an area on which rescue personnel can safely work on the craft and place any necessary equipment.

The objective of the ACRV stabilization system is to provide for the stabilization and damping of the rotational and linear motions induced through sea and weather conditions. These motions are roll, pitch, and yaw for rotational motions and heave, surge, and sway for linear motions. Considering the circular symmetry of the Apollo design, roll and pitch can be considered the same motion.

The range of motion to be stabilized is characterized by the frequency of the disturbance. Vibrations due to ocean-wave excitation of a hull occur primarily at fundamental frequencies between 1 and 3 Hz. The resonant frequency of a human is approximately 2-5 Hz[2]. This places the frequency range of the disturbances within the resonance frequency range of a human, which may tend to stimulate motion sickness of the crewmembers.

The circular symmetry of the proposed ACRV presents a problem that is not encountered with typical ocean vessels. The roll in a ship only manifests itself in one direction, a plane normal to the deck. The motion of an ACRV is characterized by roll and pitch and may occur in any plane normal to the craft planform area. The stabilization systems developed for the control of ship roll only work for one direction[3]. The ACRV needs systems to dampen motions in all directions. This requirement limits the feasible choices for an effective ACRV stabilization subsystem.

The third major concern is associated with providing full medical support to an ill, injured, or deconditioned crewmember aboard the ACRV from the time of separation from the Space Station to rescue by recovery forces. While living and working on the Space Station, the astronauts will be involved in extravehicular activities and other demanding jobs. It is likely an injury may occur that requires emergency medical care available only at a hospital on Earth.

Since the ACRV must bring an injured crewmember back to Earth safely, it must be designed and equipped to handle any possible medical emergency. It must provide full medical support to a seriously ill or injured crewmember and partial support to a crewmember with minor injuries during the time period between separation from the Space Station to crew recovery on Earth.

The medical support subsystems must be as simple and easy to use as possible. In the case of an emergency, the astronauts should not spend time making the medical systems work properly. If the crew has been in space for an extended period of time, they will be deconditioned and not function well in the gravity of Earth without assistance. Another major requirement is that the medical support subsystems be capable of operating without adverse effects on other ACRV subsystems or the ACRV crew compartment and environment.

The medical equipment for the ACRV consists of the devices needed to maintain and/or monitor the crewmember's condition. The minimum medical equipment to be incorporated into the ACRV includes defibrillator/heart monitor, IV pump, ventilator, blood pressure monitor, portable suction, and blood oxygen monitor.

Since the EEC is a self-contained system, the administration, control, and removal of oxygen will be emphasized at the seat locations. The seat locations differ from the couch location in that a crewmember may need only pure oxygen administered at the seat and not require use of the EEC.

Finally, the fourth major concern is providing for the comfort and safety of the entire crew from splashdown to the time of rescue. The rescue team may not arrive at the craft for an extended period of time. Therefore, maintaining the comfort and health of the crew within the ACRV is necessary. If the ACRV and its crew must remain on the water for 24 hours, then food, water, and waste management systems need to be incorporated. An atmospheric and environmental control system to maintain a shirtsleeve environment also needs to be incorporated.

Providing a food supply for the ACRV system is important. Although humans can survive for weeks without food, ill, injured, or deconditioned crewmembers may suffer if proper nutrition is not provided. Factors used in choosing ACRV food supply systems include shelf life, nutritional value, weight, size, taste, and system complexity.

Water is important to the crew for consumption and washing. Requirements for the amount of drinking water vary. Factors used in choosing water systems candidates are size, weight, complexity, and existence of the needed technology.

Waste management is important to the ACRV systems to provide for crew comfort and to prevent contamination. Factors used to choose the system types are weight, size, complexity, simplicity, and existence of required technology. Convenience is also considered since experience has shown that inconvenient waste elimination systems encourage the desire to avoid these systems by not eating or drinking.

The atmosphere inside the ACRV will conform to conditions present on Earth at sea level. This means the O_2-N_2 mix will be 20-80%, and the cabin pressure will be set at 14.7 psi. Systems used can be modeled after the atmosphere systems of the Skylab, space shuttle, and Hermes (European Space Plane) vehicles.

The contaminant control system removes known contaminants, odors, and CO_2 from the atmosphere aboard the ACRV. A most challenging task is the postlanding control of temperature, humidity, and ventilation. The regulation of these environmental components is a crucial factor in the success of the ACRV in the ambulatory mission.

When the craft lands, it is assumed that all avionics systems will be turned off except for a position beacon and local two-way communications equipment. The life support electronics are all solid-state low-power systems. Therefore, the initial thermal model will only include the body heat generated by a crew of two, which can be estimated using ASHRAE tables[4]. Body heat production is highly dependent on the activity level.

The primary problem with postlanding spacecraft temperature controls is that the mode of heat expulsion used in space will not work on the Earth's surface. The heat expulsion system in space takes advantage of the low temperature in the shade from the sun and near-vacuum air pressures. The radiators are usually mounted on the inside of the craft's skin to route the coolant fluid as close as possible to the radiative surface, the craft's outer skin. The coolant leaves the radiators and flows through the flash evaporators. When the radiators cannot expel the total heat load, the flash evaporator is activated. Cooling is accomplished by throttling liquid water to the near-vacuum pressure of space. The water boils and the steam is expelled from the craft. The latent heat of steam and the mass transfer from the craft completes the heat expulsion process.

During reentry, the radiators become less effective due to the heating of the craft's skin and the increase of the atmospheric temperature. In addition, the flash evaporator becomes less effective since the atmospheric pressure increases as the ship descends. At 100,000-ft elevation, the space cooling system becomes ineffective.

The time period of concern for this section of investigation begins when the craft has landed. However, some consideration will be given to the cooling system design for the several minutes before landing when the space cooling system is inoperable. Although flash evaporation does not occur below 100,000 ft, it is recommended that the primary thermal control system in the atmosphere be provided with an alternative heat sink.

DESIGN SOLUTIONS

Crew Egress and Rescue Personnel Support

The design solutions associated with rapidly and safely removing a sick or injured crewmember from the ACRV and providing rescue personnel support will be addressed first. The hardware involved consists of an EEC, a mechanism to facilitate the removal of the couch, and the associated rescue support.

EEC is a specially designed couch for the ACRV medical mission and is termed the Special Purpose Couch (Fig. 1). The portion where the injured crewmember's legs reside is elevated with fully supine positioning from the hips up to aid in trauma cases. A hard cover with access ports encloses the structure providing a self-contained environment within. Provisions are made within the couch to accommodate medical equipment and data transmission devices. Material considerations ensure that the couch attains a positive buoyant nature should a mishap occur where the couch escapes into the water.

To facilitate the safe and rapid removal of the couch, the Four Link Injured Personnel Mechanism (FLIPEM) has been designed. The FLIPEM is a set of four bar linkages connected on both sides of a horizontal platform used to support the couch (Fig. 1). Once initiated, retaining latches release the

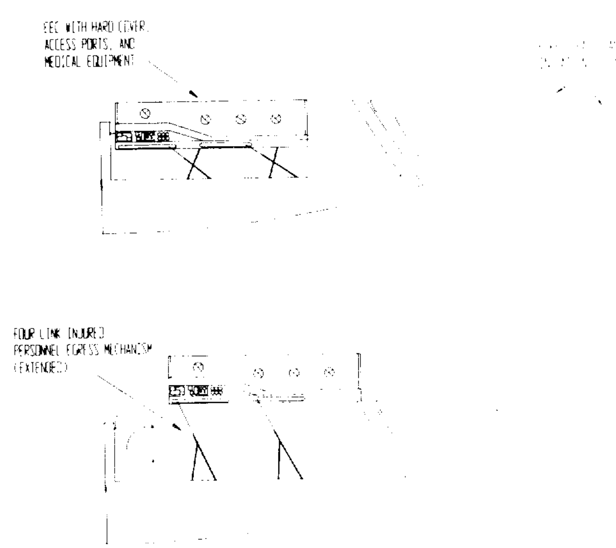

Fig. 1. Four-Link Injured Personnel Egress Mechanism and Emergency Egress Couch System

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FLIPEM where nitrogen-charged piston cylinders drive the mechanism a set distance to the hatch opening. Ratchet locking systems are incorporated to prevent retraction. After removal of the couch to the rescue ships, the platform used for the couch aids the remaining crewmembers in their egress.

The rescue personnel system configuration consists of a set of handholds and footholds to provide a source of secure footing, and D-rings to provide points for safety line attachments to aid the rescue personnel. Retractable tethers are also incorporated to support both the divers and couch with a safety line for use during rough sea conditions.

Orientation, Attitude, and Stabilization Systems

The three-balloon orientation system utilized during the lunar program is chosen to attain the proper orientation of the Apollo craft after splashdown. Three 6.2-ft diameter balloons, deployed from the top of the ACRV, upright the craft and provide double redundancy in case of single balloon failure. Individual canisters, activated manually or automatically, provide the 375 cu ft of CO_2 needed for inflation.

Attitude control is accomplished by a system consisting of three multichambered segments. Each segment extends a third of the way around the perimeter of the craft. One segment of the ring resides under the egress hatch and has a $6 \times 6 \times 3$-ft rectangular appurtenance. This appurtenance acts as a platform on which to place the couch before removal by the rescue ship, and as a platform for use by the rescue personnel. Individual canisters of CO_2 are used to inflate the rubberized woven Kevlar ring system.

The stabilization of the ACRV during adverse sea and weather conditions is accomplished by a deployable underwater parachute system. The basic premise of this system is that damping occurs through a weight force creating a moment. As the craft oscillates, the parachutes are forced to move large volumes of water. As the energy of the motion is dissipated by overcoming the inertia of the water and through shear and drag forces, the craft will be stabilized.

The parachute system is housed in the same compartment as the attitude ring system and deploys in conjunction with it. The parachutes are attached to cables that are weighted with segments of the ACRV skin. Three long cables are extended approximately six feet below the water line to avoid the wave action zone. The possibility of entanglement increases if more cables are added or their length increased.

Three additional parachute-cable systems are deployed to a depth just below the water line. These act to resist the heave and pitch motions of the craft, while the longer cables reduce the yaw and surge motions. The entire orientation, attitude, and stabilization systems can be seen in Fig. 2.

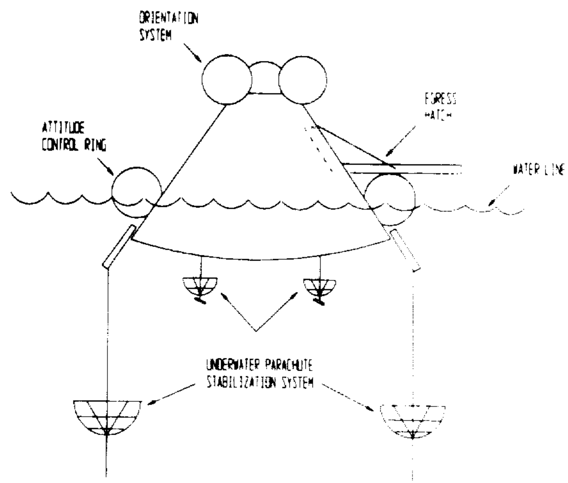

Fig. 2. Complete Orientation, Attitude, and Stabilization System

Medical Support Systems

This portion of the report addresses solutions to the partial medical support package, necessary medical equipment and monitors, and the oxygen administration and control systems. The Thomas Transport Pack was determined to be sufficient for use as the partial medical support package. This system is similar in configuration to the full-sized backpacks used by hikers. Currently, the Thomas Pack is employed aboard the shuttle fleet for the same type of application.

Extensive research was performed to evaluate suitable, "off-the-shelf" medical support equipment and monitors. As a result, several brand names were selected that conformed to the ACRV program requirements. Selections were also made for a defibrillator/heart monitor, IV pump, ventilator, blood pressure monitor, portable suction, and blood oxygen monitor. For all the selected equipment rubber isolators and honeycomb pads are incorporated to provide reduction to the loadings encountered during splashdown.

Each piece of equipment operates off a standard DC, 12-V source. The Apollo craft supplies both an AC and DC power source to run all flight systems. The Apollo DC source runs at a higher voltage; therefore, a modification is required to run the 12-V equipment. After the couch is removed from the FLIPEM, two 12-V Ni-Cad batteries function to supply power (for six hours) to the equipment. If all equipment is functioning the required power is approximately 80 W.

A deconditioned crewmember positioned on a normal flight couch, requiring only pure oxygen, will use a nasal cannula device to administer the oxygen. The nasal cannula is made up of one tube that separates into two tubes. The two tubes reside in the nostrils of the crewmember and are held in place by friction. The excess oxygen that is released from this system is filtered out by an air-dump device that captures the additional oxygen and expels it to the exterior of the craft or stores it in tanks.

Crew Comfort and Environmental Control Systems

Design solutions for the food, water, and waste management, atmosphere, contaminant/odor, and environmental control systems are addressed.

Food systems rely on space shuttle contingency bars for their proven application and low volume and weight. Water supply systems utilize plastic squeeze bottles for their ease of use and storage. The waste management system stems from a derivative of the Apollo-style waste bag system. Slight modifications to this system are necessary to qualify for use by both men and women.

Atmosphere and contaminant/odor control systems are derived from existing systems already in use. The atmosphere control system is based on the Skylab atmosphere system. This system uses oxygen and nitrogen tanks, stored at 3000 psi and regulated through valves, to provide the appropriate atmosphere. ACRV program requirements specify that a 14.7 psi (Skylab: 5 psi) atmosphere be maintained throughout the mission. Charcoal and lithium-hydroxide filters, used aboard the shuttle, will be used to scrub the air for odors and CO_2.

Maintaining environmental control within the ACRV throughout the mission is accomplished by flash evaporation with water above 100,000 ft and flash evaporation with ammonia below 100,000 ft. Below 100,000 ft, the primary heat source runs through an ammonia boiler system that has been precooled at the space station, instead of through the radiator used in space. Though a precooled system is more efficient than a non-precooled system, the added complexity of interfacing with the space station coolant system will demand greater costs and design time. It is estimated that 116 lb of ammonia in a spherical tank would be required to maintain a comfortable temperature within the ACRV for a calm crew of two with no equipment (other than medical) running for a period up to 24 hours.

SUMMARY

This report addresses and provides solutions to the design considerations associated with the postlanding crew and medical support for a water landing ACRV. After splashdown has occurred, the orientation balloon system deploys, righting the ACRV (if needed) and maintaining it in the proper orientation. Then the attitude control ring is activated. The inflation of the ring forces the arms of the underwater parachute stabilization system to rotate out of their compartments and deploy the parachutes. The parachutes are attached to segments of the discarded ACRV skin, which forces the tension in the cables. Six parachute-cable systems are deployed in all. Three parachute-cable assemblies drop to 6 ft under the surface of the water to control the motions of yaw and surge. The remaining assemblies drop to approximately 1 ft under the surface to control the motions of heave and pitch.

The medical support equipment and monitors will function throughout the entire mission from separation to recovery. The ammonia boiler environmental control system that is used to maintain a shirtsleeve environment inside the craft after splashdown is activated passing through 100,000 ft and functions until recovery. Food, water, and waste management systems are incorporated in case rescue is not immediate. Following hatch opening by the rescue personnel, the FLIPEM releases to deliver the medical couch to the hatch opening. The rescue personnel remove the couch along rails in the hatch and extension to a safe distance for attachment to cables used to lift the couch to the recovery ship. The remaining crew members exit using the platform left by the use of the FLIPEM.

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