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DESIGN, BUILDING, AND TESTING OF THE POSTLANDING SYSTEMS FOR THE ASSURED CREW RETURN VEHICLE

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The design, building, and testing of the postlanding support systems for a water-landing Assured Crew Return Vehicle (ACRV) are presented. One ACRV 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 configuration of the ACRV is based on an Apollo Command Module (ACM) derivative. The 1990-1991 effort concentrated on the design, building, and testing of a one-fifth scale model of the egress and stabilization systems. The objective was to determine the feasibility of (1) stabilizing the ACM out of the range of motions that cause seasickness and (2) the safe and rapid removal of a sick or injured crewmember from the ACRV. The development of the ACRV postlanding systems model was performed at the University of Central Florida with guidance from the Kennedy Space Center ACRV program managers. Emphasis was placed on four major areas. First was design and construction of a one-fifth scale model of the ACM derivative to accommodate the egress and stabilization systems for testing. Second was the identification of a water test facility suitable for testing the model in all possible configurations. Third was the construction of the rapid egress mechanism designed in the previous academic year for incorporation into the ACRV model. The fourth area was construction and motion response testing of the attitude ring and underwater parachute systems.

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, an ambitious and far reaching program to further the advancement of space technology has been launched. With Space Station *Freedom*, the United States enters an era marked by a permanent presence in space. The space station allows continuous rather than intermittent operations to be conducted in orbit. The space station opens doors to many new methods of research and experimentation. Included are better opportunities to observe the Earth and forecast future trends from a vantage point only partially exploited by previous shuttle missions.

Space Station *Freedom* is planned to have a permanent crew of four. The crew will be rotated and resupplied by flights of the Orbiter on an interval currently planned for three months. Because of 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; and/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 were developed in conjunction with Kennedy Space Center ACRV project managers and are limited to what is required for a water landing ACRV and postlanding operations. The configuration of the ACRV is based on an Apollo Command Module (ACM) derivative. The designs presented are associated with the development of one-fifth scale models of the ACRV egress and stabilization systems developed at the University of Central Florida during the 1989-1990 academic year.

UCF ACRV DESIGNS DEVELOPED PREVIOUSLY (1989-1990)

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 may compromise the mission. Following are general design considerations and solutions investigated by the senior-level Mechanical and Aerospace Engineering Design classes during the 1989-1990 academic year. The design considerations were from the point immediately after splashdown to rescue by recovery forces.

The first consideration was providing crew egress and rescue personnel support subsystems to ensure the safe and rapid removal of an ill or injured crewmember from the ACRV by recovery forces. A Special Purpose Emergency Egress Couch was designed to medically support a sick or injured crewmember during the ACRV mission. This couch provides a self-contained environment and space for necessary medical equipment. To aid in the movement of the couch from the ACRV floor to the hatch location, a Four Link Injured Personnel Egress Mechanism (FLIPEM) was developed. Support to the rescue personnel is provided by the placement and design of properly located handholds, supports, and platforms.

The second consideration was the proper orientation, attitude control, and stabilization systems required for the ACRV in the marine environment. Experience gained from previous Apollo water landings showed that some sea and weather conditions cause severe discomfort to the crew. In the case of an injured crewman this may cause further aggravation of an existing injury, or even death. Postlanding orientation of the ACRV is achieved through the use of three, 6.2-ft diameter, CO_2-charged balloons similar to those used during the Apollo program. Attitude control systems were designed that automatically deploy three multichambered ring segments. One segment resides under the hatch and has a 6×6×3-ft appurtenance to act as a stable platform for the rescue personnel. Multiple underwater parachute assemblies were designed to provide motion reduction through the principles of inertia and viscous drag associated with moving large volumes of water.

The third consideration dealt 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 that an injury may occur that requires emergency medical care available only at a hospital on Earth. Partial medical support, medical support equipment and monitors, and oxygen administration and control systems were addressed. Partial medical support is accomplished by employing the Thomas Transport Pack currently used aboard the shuttle. Extensive research was performed to select suitable medical support equipment and monitors as required by NASA. Each piece of equipment was integrated into unified packages and power requirements were addressed. Oxygen is supplied to a deconditioned crewmember, seated at a regular flight couch, by a nasal cannula and excess oxygen filtered out by an air-dump system. The medical couch is supplied by an independent O_2 system for a period of six hours after egress.

The rescue team may not arrive at the craft for an extended period of time. Consequently, the fourth consideration was to provide for the comfort and safety of the entire crew from splashdown to the time of rescue. Addressed were design solutions for food, water, waste management, atmosphere, contaminant/odor control, and environmental control systems. Food systems chosen rely on space shuttle contingency bars for proven application and low volume and weight. Water supply systems use plastic squeeze bottles. The waste management system is a derivative of the Apollo-style waste bag system. Modifications are necessary to qualify for use by men and women. The standard sea-level atmosphere inside the ACRV is generated by a system using two 3000-psi tanks of O_2 and N_2. The contaminant and odor control design uses lithium hydroxide and charcoal filter systems used extensively in the space program. An ammonia boiler environmental control system was designed to supplement the existing system after the craft descends through 100,000 ft to the time of rescue.

1990-1991 UCF ACRV DESIGN TASKS

During the 1989-1990 year, the Engineering Design classes examined solutions in support of postlanding operations for the ACRV. The 1989 fall semester class selected designs in the areas of (1) crew egress and rescue personnel support, (2) orientation, attitude control, and stabilization, (3) medical support systems, and (4) crew survival systems. The 1990 spring semester class, with new students, was responsible for providing greater detail to the designs selected in the fall semester. The design requirement was increased in the 1990-1991 academic year from one semester to two semesters. The students participating in the conceptual design during the fall semester now continue with building and testing in the spring semester. The task objectives for the 1990-1991 Engineering Design class were to determine the feasibility of the previously developed egress and stabilization systems for deployment on the ACRV. Working models of these systems were designed, built, and tested. The scale selected for the development of these systems was one-fifth. Four design teams were formed and tasked as follows:

Design Team #1—ACRV Model Construction

The responsibility of the ACRV Model Construction team was to design, build, and test a one-fifth scale model based on the Apollo Command Module (ACM) such that the egress and stabilization systems can be incorporated and tested. The model was required to accurately simulate the geometric and dynamic characteristics of the ACM derivative for testing purposes.

Design Team #2—Water Test Facility Identification

The Water Test Facility team was responsible for identifying a test facility where stabilization tests on the ACRV model can be performed. This included researching existing facilities as well as establishing designs for a permanent facility at the University of Central Florida. As a result of the investigation an existing facility was selected for testing and the building and testing phases of a permanent facility were not pursued.

Design Team #3—Rapid Egress Systems

The objective of the Rapid Egress System team was to design, build, and test the Four Link Injured Personnel Egress Mechanism (FLIPEM) optimized during the previous year. The FLIPEM consists of three parts: the lift mechanism, the extension support mechanism, and the restraint mechanism. The lift mechanism must translate the couch platform from the ACRV floor to the hatch location. The extension support mechanism provides the means to move the couch platform a specified horizontal distance out of the hatch for recovery. The restraint mechanisms are required to ensure the FLIPEM remains in the stowed position prior to deployment, and to prevent movement of the couch on the platform during FLIPEM operation.

Design Team #4—Stabilization Control Systems

The objective of the Stabilization Control Systems team was to determine, through modeling, the feasibility of reducing heave, surge, and pitch motions of the ACRV model on water using an underwater parachute system. The underwater parachute system should stabilize the ACRV out of the range of motion that causes seasickness to prevent further injury or illness. This range is approximately 0.2-0.5 Hz. Associated with the underwater parachute system are the attitude ring and mattress. The attitude ring is a buoyancy control device attached to the

ACRV to aid in flotation and stabilization. The attitude ring mattress is located under the hatch and acts as a stable platform for recovery operations.

1990-1991 UCF ACRV DESIGN, BUILDING, AND TESTING RESULTS

ACRV Model Construction

The ACRV Model Construction team designed, built, and tested a one-fifth-scale model based on the ACM derivative. Data for the weight and geometric dimensions of the ACM derivative were supplied by Rockwell International. Three design considerations were incorporated in the construction of the model. These were (1) shell construction, (2) center of gravity and mass moment of inertia of the system, and (3) hardpoint accommodations.

The shell for the ACRV model was constructed in two parts. The first part consisted of developing two molds that represent the upper and lower halves of the model. Technical support during this phase of the construction was supplied by Guard-Lee, Inc. located in Apoka, Florida. The molds were constructed using wood frames with PVC foam inserted to form the outline of the two halves. Resin and bondo material were then applied to arrive at the smooth shape required for shell lay-up. The second part of the construction process was the shell lay-up. The lay-up of the fiber-glass composite shells was contracted out to Guard-Lee, Inc. The upper and lower halves of the model were attached using a four-bolt/T-nut system with a weather stripping material for the sealing gasket.

The center of gravity and mass moment of inertia were modeled using a system of flat circular plates located in the model. The size and weight of the plates required were determined from pendulum tests performed on the empty shell, from which the mass moment and c.g. location could be found. As a result, three 19-in diameter steel ring plates were affixed to the bottom of the model floor, two 5.25-in steel plates were affixed to the inside top, and three to the inside bottom of the model. The c.g. was varied by attaching the large ring plates to slots cut in the floor. Also incorporated in the model was a point mass system to duplicate the motion of the egress mechanism. This system will allow for measuring the pitch angles caused by the operation of the egress mechanism.

To incorporate the egress and stabilization systems, the model was designed and built with the necessary hardpoints and attachments. A series of eye hooks were positioned around the periphery of the model just above the breakline, which were used for attachment of the stabilization systems during testing. To distribute the load caused by the stabilization systems, hardpoints were installed at the eye hook locations. The hardpoints consisted of 4 × 4 × 4-in blocks of wood located on the interior of the model into which the eye hooks were drilled. The wood blocks were reinforced by a fiberglass encasement. The hardpoints for the egress mechanism required only holes drilled into the floor of the model.

A test plan was developed to verify the fidelity of the ACRV model as an operational testbed. The test included size and weight verifications, seal integrity, inspection of hardpoint accommodations for the egress and stabilization systems, c.g. variability, and mass moment verification.

Test results indicate small deviations from the size and weight specifications provided by Rockwell International. Hardpoint accommodations and seal integrity were maintained throughout the approximately 30 hr of water testing on the egress and stabilization systems.

Water Test Facility Identification

The Water Test Facility Identification team researched test facilities where stabilization tests on the ACRV model could be performed. This research included examining existing facilities and developing designs for a permanent facility at the University of Central Florida.

As a result of this investigation, stabilization testing with the ACRV model was performed at the O.H. Hinsdale Wave Research Laboratory (WRL) at Oregon State University in Corvallis, Oregon. O.H. Hinsdale WRL satisfied a majority of the requirements needed for testing. The facility was available during the planned testing period from April 1-5. The dimensions of the wave pool (342 × 12 × 15 ft) supported testing of the ACRV model in all configurations. Regular and irregular waves of periods from 1.0 to 10.0 s and wave heights up to 5.0 ft could be generated. A moveable carriage equipped with a platform and a 5.0-ton hoist moved the model into and out of the water. Visual records were made using two underwater video cameras and a video camera located in the elevated control room. Instrumentation such as accelerometers was connected to a computerized data acquisition system. The full-time staff of ocean engineers provided excellent technical support throughout the testing period. Financial support for travel, lodging, and facility fees was provided by a grant from Rockwell International.

Rapid Egress Systems

The Rapid Egress Systems team designed, built, and tested a one-fifth-scale working model of the Four Link Injured Personnel Egress Mechanism (FLIPEM) optimized in the previous academic year. FLIPEM consists of three parts: the lift mechanism, the extension support mechanism, and the restraint mechanism.

The lift mechanism employs two compressed air cylinders each capable of lifting the entire system. When activated by radio control the cylinders located beneath the couch platform extend the FLIPEM the required horizontal and vertical distance from the model floor to the hatch location. Built-in ratchets ensure one way motion and can be released to allow for manual retraction. The Two-Slider Support Mechanism (TSSM) provides the extension support of the couch platform through the hatch to a distance away from the model. The sliders, similar to those used on a tool box, are extended by a means of a reversible electric motor and a cable-pulley system. The restraint mechanism employs a spring-loaded hook, activated by radio control, to maintain the FLIPEM in the stowed position, and a series of locking pins to prevent movement of the couch platform during FLIPEM operation. The FLIPEM is shown in Fig. 1.

Operational and visual testing were performed at UCF. Testing was conducted in the areas of lifting force with nominal and off-nominal loads, vertical and horizontal travel distances,

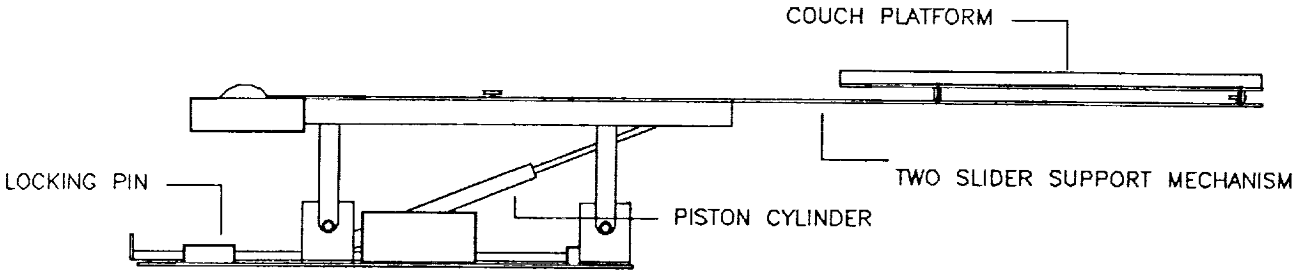

Fig. 1. Four Link Injured Personnel Egress Mechanism.

redundancy characteristics of the FLIPEM and extension force, travel distance, and redundancy characteristics of the TSSM. Test results indicate the design specifications for both systems were met or exceeded and without interference to other systems.

Stabilization Control Systems

The Stabilization Control Systems team designed, built, and tested one-fifth scale models of the attitude ring and underwater parachute stabilization system optimized during the previous year. The attitude ring proposed for the actual ACRV is composed of six inflatable spheres. The inflatable spheres were modeled using 8-in-diameter tether balls. The tether balls are connected to eye hooks located around the periphery of the model. The underwater parachutes, with diameters from 1 to 2.5 ft were constructed using nylon fabric and string. The parachutes were attached to eye hooks located on the model with stiff and elastic cables of 3-ft length. Fishing weights were attached to the parachute assemblies to aid in deflation of the chutes on the downstroke. Devices were designed and built to be attached to the parachute openings to decrease the amount of distance required to inflate the chutes on the upstroke. Three mechanical accelerometers were attached to the model floor to measure heave, surge, and pitch.

Wave testing in simulated sea states 2 to 4 at the O.H. Hinsdale WRL yielded results that indicate that the six-attitude sphere configuration produced minimal stabilizing effects on the ACRV model. The spheres did have the effect of enhancing the flotation characteristics of the model.

Pretesting at UCF on the inflation distances of the parachutes showed that the 1-ft-diameter chutes would open almost immediately and the 1.5-ft diameter chutes required nearly 3 ft of stroke to open. The larger diameter parachutes would not open in the 6-ft stroke tested. As a result of this inflation testing only the 1- and 1.5-ft-diameter parachutes were tested in the simulated sea states at O.H. Hinsdale WRL. Numerous parachute arrangements, including single and multiple chutes per cable, increasing the weight attached, using stiff and elastic cables, and devices to partially and totally open the chutes, were tested. Results indicate that the parachutes did affect the motions induced on the model, but did not reduce or increase the frequencies out of the range that causes seasickness.

SUMMARY

The 1990-1991 senior-level Mechanical and Aerospace Engineering Design class completed the one-fifth-scale design, building, and testing of the postlanding egress and stabilization systems for an Apollo Command Module-based ACRV. The objective was to determine the feasibility of (1) stabilizing the ACRV out of the range of motions that cause seasickness and (2) the safe and rapid removal of a sick or injured crewmember from the ACRV. Work was conducted in the following areas: ACRV model construction, water test facility identification, and stabilization control systems.

A one-fifth-scale working model of an Apollo Command Module (ACM) derivative that accommodates the egress and stabilization systems was designed and built by the ACRV Model Construction team. The fidelity of the model was established from geometric and dynamic characteristic tests performed on the model. Results indicate small deviations from the specifications provided by Rockwell International.

Stabilization tests on the ACRV model were conducted at the O.H. Hinsdale Wave Research Laboratory (WRL) at Oregon State University as recommended by the Water Test Facility Identification team. The testing period was April 1-5, 1991. The facility accommodated all testing configurations and the staff provided excellent technical support.

The Rapid Egress Systems team designed, built, and tested one-fifth-scale working models of the Four Link Injured Personnel Egress Mechanism (FLIPEM) and the Three Slider Support Mechanism (TSSM). Operational and visualization tests confirmed that the lifting force, travel distances, and redundant characteristics of both systems met or exceeded the design specifications for their operation.

The ACRV attitude ring and stabilization system models were designed, built, and tested by the Stabilization Control Systems team. The responses of the attitude ring/model and the parachute/model combinations when compared to the baseline dynamic response of the model itself show they had no effect on reducing the oscillations of the model in the simulated sea states 2, 3, and 4.

A concept employing Rocker Stoppers was built and tested at the water test facility to determine the effect a rigid system would have on reducing the oscillations. Two Rocker Stoppers were connected, nose-to-nose, at one end of a long threaded rod. The other end of the rod was connected to a metal plate attached to the model above the breakline. Four of these arrangements were connected to the model. Since the Rocker Stoppers (Fig. 2) are made of rigid plastic, they perform the same work on the upstroke as on the downstroke. This configuration was tested in a simulated sea state 4 (1.2 ft amplitude, 0.45 Hz) and the response compared with that from the clean model in the same sea state. The results indicate that a rigid system in this configuration does reduce the oscillations the model experiences. The frequency of the pitch motion dropped from 0.45 Hz to 0.40 Hz with the Rocker Stoppers attached. This reduction is below the simulated range (0.45-1.1 Hz) associated with seasickness.

Several recommendations are suggested for future design projects in the area of postlanding operations associated with the ACRV. Integrated wave testing involving the egress system and the attitude ring spheres and mattress needs to be examined. Another project would entail building and testing a full-scale egress system based on the FLIPEM design. Examining the flotation and wave motion characteristics of other ACRV configurations, such as the SCRAM and HL-20, and comparing them to a mathematical model is suggested. Finally, testing rigid stabilization systems using the Rocker Stopper concept for motion reduction shows potential for developing a damping system capable of moving the ACRV motion out of the range of frequencies associated with seasickness.

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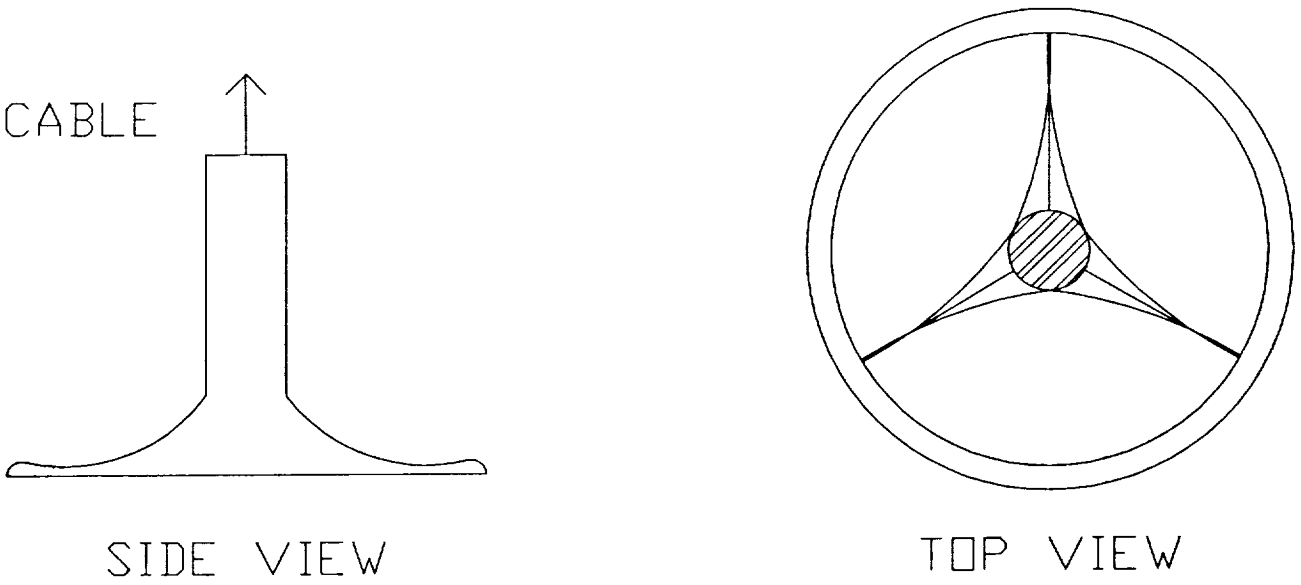

Fig. 2. Rocker Stopper Option.