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EVALUATION OF ICE AND FROST ACCUMULATION ON THE SPACE SHUTTLE EXTERNAL TANK

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ABSTRACT

Ice/frost formation on the Space Shuttle cryogenic propellant tanks presents a different problem from that of past launch vehicles. Lift off weight addition has been the primary concern on past launch vehicles. The primary ice/frost concern on the Shuttle vehicle is damage to the Orbiter Thermal Protection System due to ice/frost impact. The approach used to arrive at a solution to this unique Shuttle problem is presented. The launch vehicle configuration selected and its limitations are described, along with contingency ground support equipment.

INTRODUCTION

The accumulation of ice/frost on insulated and un-insulated surfaces of launch vehicles utilizing cryogenic propellants is well documented. It has been seen on closed circuit T.V., observed by Pad crews after propellant tanking, and recorded on launch and flight films. During launch and flight, some of the accumulated ice/frost is shed while the rest remains attached throughout the flight. The accumulation is also shed if the propellant tanks are drained.

Predicting the payload weight penalty resulting from the ice/frost accumulations has been the chief concern on past launch vehicles. The Space Shuttle has an additional and more complex concern because of its unique geometry. The ice/frost shed from the Space Shuttle External Tank (ET) ogive nose would probably hit the Thermal Protection System (TPS) of the piggyback orbiter vehicle. Figure 1 shows the complex configuration of the Shuttle vehicle while being serviced on the launch pad.

The TPS is comprised of thousands of delicate, ceramic coated, tiles designed to protect the Orbiter and Astronauts from the scorching heat generated during re-entry into the earth's atmosphere. Damage to the TPS during launch or flight can result in a flight safety problem and extensive Orbiter post flight refurbishment.

This paper presents an overview of the programmatic approach used to resolve this critical Space Shuttle problem.

BACKGROUND

The ET was originally baselined with insulation to protect against ascent heating and prevent the formation of liquid air during and after loading of

the cryogenic propellants, liquid oxygen (LOX) and liquid hydrogen (LH₂). Therefore, one-half inch of spray-on-foam-insulation (SOFI) was specified for the LH₂ tank sidewalls and aft bulkhead. In addition, an ablative material was specified for the aft bulkhead of the LH₂ tank as well as the ogive area of the LOX tank, which is located at the forward end of the ET. The ablative material was also applied to the inert tank area between the LOX and LH₂ tanks. The cylindrical portion of the LOX tank was left uninsulated as well as all ET to Orbiter and ET to Solid Rocket Boosters (SRBs) attach links.

Early developmental testing determined the orbiter TPS tiles would very likely be damaged if impacted by ice/frost falling from the ET. With the baseline ET insulation, falling ice/frost was a virtual certainty.

DETERMINING THE PROBLEM'S MAGNITUDE

Once the problem was posed, engineers at Downey, California, working under the direction of the Orbiter Project Office at the Johnson Space Center (JSC) Houston, Texas, performed some crude tests to determine the TPS's susceptibility to damage from falling ice/frost. The tests indicated a one inch cube of ice falling four inches would crack the tile's ceramic coating.

Simultaneously, the Shuttle Program Integration Office at JSC initiated a companion study supported by engineers in the ET Project Office at the Marshall Space Flight Center (MSFC), Huntsville, Alabama, and the Shuttle Project Office at the Kennedy Space Center, Florida. This study was aimed at identifying flight and ground systems which could be used to prevent ice or prevent falling ice/frost from impacting the Orbiter TPS.

The flight concepts considered included ET insulation adequate to prevent frost, shields supported from the Solid Rocket Boosters, heater blankets on the ET, and a special conductive heater paint powered from the ground to prevent ice/frost accumulation. Also considered were several phobic coatings which could be applied to control the buildup and shedding of ice/frost.

The ground systems considered ranged from large clamshell enclosures and heated air curtains to a variety of flexible bags which could be purged with dry gaseous nitrogen or air. These were intended to isolate the ET surface from the moisture laden

ambient air. The nature of these concepts required them to be in place until very near lift-off since ice/frost would begin to form once the uninsulated surfaces of the ET were exposed to the ambient air. This necessitated expensive and complex equipment for rapid removal of the isolation system.

Heating the ET surface with ground systems was also considered. However, with portions of the tank uninsulated, the heating requirement became impractical and the boil-off rate of the cryogenic propellant greatly increased. This increase impacted the ET vent system size.

In parallel scientists at the ET Project Office (MSFC) initiated a statistical survey of the environments at the two Space Shuttle launch sites, the Kennedy Space Center and Vandenberg A.F.B. California. A thermodynamic math model was developed relating all of the tank design and environmental conditions which affect the ET surface temperature, eg., insulation thickness, wind speed, ambient temperature, humidity, and thermal radiation environment. The model would be used to optimize the ET insulation thickness and determine the effect of a supplemental heating system.

No single simple system or solution was identified which totally solved the problem. Additional insulation on the ET was required even though it added weight to the flight vehicle. This additional insulation did not provide a solution for the coldest weather conditions; however, it made supplemental non-flight heating systems feasible.

BASELINE CONFIGURATION CHANGE

The Shuttle Program Manager at JSC directed a change to the ET as a result of the preceding analysis and environmental data review. In its new configuration, the ET will have a minimum of one inch of SOFI over its entire surface.

This decision allowed the design and planning for all phases of the Space Shuttle Program to continue. However, some important questions still remained unanswered.

1. Were there risks to the Space Shuttle program posed by the baseline change?
2. Were there feasible ground systems which might be implemented if needed to provide an all weather launch capability?
3. Could a conductive heater paint be used to eliminate a weather launch constraint?
4. What were the physical characteristics and the damage potential of the ice/frost which might form on the insulated cryogenic tanks?
5. Could the weather data be refined for the launch sites?
6. What were the launch probabilities based on the refined weather data?

ASSESSMENT OF BASELINE CHANGE

In order to assess risks and launch probabilities associated with the baseline change, the launch schedule impacts due to weather had to be understood. Engineers and meteorologists at MSFC, therefore, initiated an effort to further develop and understand the environmental conditions of both KSC and VAFB. This effort provided a ten year weather history for KSC which, when used in conjunction with the thermodynamic math model, would allow probability predictions for the formation of ice/frost on the external tank. The effect on launch probability of heat applied to the ET could also be determined. The results were compared with the Space Shuttle program requirement for a ninety five percent launch probability. A launch probability of eight five percent was determined to exist for the environmental conditions at KSC during the coldest hours of the coldest month. However, since most launches do not occur during this time, the overall impact for KSC was determined to be only two launch delays during the projected ten year Shuttle program.

The data for analyzing the environment at VAFB, was incomplete. Therefore, no launch probability assessments were made for that site. Action, however, has been taken to accumulate the data for this analysis.

SUPPLEMENTAL GROUND SYSTEMS

The math model indicated that ten watts per square foot of externally applied heat would increase the launch on time probability at KSC to greater than the required ninety-five percent. Ground systems for adding the required heat were evaluated by engineers at KSC. Two systems appeared feasible. The first used the existing twenty kilowatt Xenon launch pad searchlights focused on the ET. Some of these lights are already required for nighttime operations. This system required that the ET be painted black. The second involved the use of an ambient temperature water shower above the ET.

Using searchlights for heating was simple from a facility point of view since the searchlights were virtually self contained and were portable. They also had the operational advantage of being passive in that the system did not have to be terminated or retracted at lift-off. A detailed analysis indicated the majority of the exposed surface area, which was of concern, could be heated using fifty searchlights placed in six arrays six hundred feet from the vehicle. The searchlights were sited to compensate for the shadowing effect of the Shuttle Service and Access Tower (SSAT) and the Payload Changeout Room (PCR) at the launch pad and to protect them from the blast during launch. The only area not receiving the minimum of 10 watts per square foot was a narrow strip of the ET adjacent to the SRBs and the side of the ET away from the orbiter and aft of the inner tank area. Ice/frost on these areas was not expected to impact the orbiter.

The shower system had a large facility impact in terms of permanently installed equipment and also produced undesirable side effects. Although analysis and preliminary small scale tests indicated the concept was feasible, adequate water distribution would have to be verified using a full scale test setup. Also, the undesirable side effects associated with water intrusion into the Orbiter would have to be further evaluated. This system also has the disadvantage of interfering with visual observation of the launch vehicle during the final phases of the launch countdown. The major advantage of the system lies in its relative cost insensitivity to changes in the actual heat requirement.

SUPPLEMENTAL FLIGHT SYSTEM

At the MSFC ET Project Office, engineers investigated applying conductive heater paint over the ET insulation to provide supplemental heating. Electrical power for the system would be provided from the ground. The concept was determined to be feasible, however, it had several shortcomings. The heat distribution was not uniform due to variations in the paint thickness. Small scratches produced arcing and the possibility of shorts to adjacent equipment caused safety problems. Applying the paint was also very critical.

EGLIN A.F.B. CLIMATIC CHAMBER TEST

An extensive test program was initiated by MSFC engineers at the Eglin A.F.B., Florida, Climatic Chamber. The purpose of the test was to validate the thermodynamic math model against varying environmental conditions, characterize the physical properties of the ice/frost accumulations, and evaluate the effectiveness of the KSC searchlight radiant heating system and a conductive heater paint system applied to the test tank's insulated surface.

The ten foot diameter test tank was divided into quadrants to give several representative SOFI surfaces for evaluation. One surface was machined to remove its rind and provide a uniform one inch nominal thickness; a second surface was left "as sprayed" for a nominal thickness slightly in excess of one inch; the third and fourth surfaces were machined to one-half inch thickness with the fourth also receiving a conductive heater paint application. The one inch surfaces were painted black to allow evaluation of the Xenon searchlight heating system. Liquid Nitrogen was used in the tank to simulate the cryogenic propellant and thermocouples were placed on the insulation to measure its surface temperature.

Testing in the Climatic Chamber was accomplished by monitoring the SOFI surface temperature while the environmental conditions were varied. The data was then compared with the predictions from the thermodynamic math model. The type and density of the accumulated ice/frost were also determined for conditions when the SOFI surface temperature dropped below 32° F.

TEST RESULTS

Several important results were achieved from the Climatic Chamber tests. The thermodynamic model for predicting SOFI surface temperature was validated and the ice/frost formations were characterized. A maximum ice buildup of 1/16-inch or frost with a maximum thickness of 1/2-inch and a density of approximately fifteen pounds per cubic foot were observed. In all cases of frost buildup, a very tightly adhered layer of ice about 1/32-inch formed adjacent to the insulation. Preliminary indications were that the observed formations of ice/frost would not pose a threat to the Orbiter TPS.

The searchlight heating concept also proved feasible for the predicted ten watts per square foot of radiant heat. As was expected, the searchlights are practically useless in a light rain or fog.

The Eglin test also proved the conductive heater paint's feasibility as a supplemental heating system. However, during the test, the paint demonstrated many of the shortcomings previously noted.

The test tank also had an uninsulated protuberance to simulate the ET attach links, and ice formed on it as expected.

CURRENT STUDIES

Engineers at the responsible NASA centers are continuing to evaluate the magnitude of the ice/frost formation on the ET uninsulated attach links and protuberances. Insulation and electrical heaters are being assessed against the risk of allowing the ice/frost to form.

The JSC Orbiter Project Office engineers are determining the risks to flight safety and the magnitude of the refurbishment effort which would be caused by ice damaged tiles.

SUMMARY

The Space Shuttle Program has an acceptable solution to the critical issue of ice/frost formation on the large surface areas of the ET with one inch of SOFI applied. Two supplemental ground solutions have been identified for use if required for a critical launch mission scheduled during the morning hours of a cold month. The facilities are available to complete the collection of environmental data at the VAFB launch site. The data will be available in ample time to arrive at a solution before the facility is activated. The protuberance issue is under evaluation and several concepts for solving this problem have been identified. Therefore, the ice/frost accumulation problem is considered off of the Shuttle program critical list.

ILLUSTRATIONS

Figure 1. Space Shuttle on Launch Pad

In the event that the SRB begins taking on water, the umbilical will be reconnected and the SRB will again be dewatered. Following dewatering, the SRB will be towed to port by the recovery vessel, where the NP will be removed from the SRB and refurbished, if necessary.

DESIGN APPROACH

The design approach for the SRB Dewatering System included simulation modeling, a hydrodynamics analysis, materials selection options, development of a dewatering system, and a failure mode and effects analysis study.

Simulation Modeling

The technology required to develop the unmanned, remotely controlled NP envisioned for the SRB Dewatering System has been used in previous, similar vehicles. CURV III, which was used in rescuing the PISCES III manned submersible from the Atlantic seabed, is representative of such technology. This technology was adapted to meet the NASA mission requirements. Docking of the NP in an SRB nozzle is the most critical of those requirements; therefore, a simulation of the docking procedure was used to provide a basis for performance prediction, design definition, and cost reduction in preselection of major system components.

A simulation system was designed and built that supplied critical performance criteria for the selection of the propulsion system (motor location, amount of thrust per motor, thrust direction, nozzle plug mass, drag, propulsion, time delay) and operator evaluation. A graphics computer (ADAGE), and its associated hardware and software, was utilized in the development of a stand-alone, realistic simulation system using the following:

1. An image processing computer, with FORTRAN level processing capabilities and associated software, for on-line editing, compiling, and executing programs
2. Peripheral memories consisting of two tape drives and a disk unit
3. A 20-inch display console screen
4. A teletype for input and control
5. Tie-in capability for inputs from analog computers and a UNIVAC 1110 for real-time simulation
6. A joystick for operator inputs with X, Y and rotational motions allowed

For the simulation problem, the high speed processing necessary for modeling the SRB dynamics was found to be too much for the ADAGE computer to do while working simultaneously on image processing. Since the SRB's motions are independent of the NP, a magnetic tape was produced on the UNIVAC 1110

which represented the motion of the SRB as a function of time. The ADAGE, free of this time-consuming task, was then programmed to calculate the reactions that the full-size NP would make to operator inputs. It then superimposed the contents of the SRB tape to give the motion of the NP, relative to the nozzle. The operator, then, saw a simulated picture of the nozzle as seen from the TV camera mounted on top of the NP. The operator pushed the joystick, trying to maneuver the NP inside the SRB. A successful dock was indicated by the sudden inversion of the picture as the computer tried to compute negative coordinates.

The implementation of the simulation procedure on the ADAGE system was very valuable from the standpoint of gaining operator experience as well as from the technological conclusions. This modeling technique indicated that a hydraulic propulsion system was the most responsive to the docking requirement. The thruster configuration was analyzed in an X, Y system, where the horizontal thrusters were set at 90 degrees to each other, and in a rotational system, where the horizontal thrusters were parallel to each other. The advantages of the X, Y configuration were apparent immediately upon the first test run. In this configuration, docking maneuvers were superior. Also rotation of the NP and potential operator error in maintaining direction were eliminated.

Hydrodynamics Analysis

The simulation modeling produced a preliminary configuration (Figure 7) for a hydrodynamics analysis; Figure 8 shows the drag curves resulting from this first analysis. For this configuration, approximately 450 to 500 lbs. of thrust would be required to achieve the velocity of 5 fps established as design target.

The final configuration (Figure 9) provides improvement in several areas. Vertical and horizontal thrusters are paired to prevent rotational moments. Horizontal thrusters were placed as high as possible in order to bring the horizontal drag and thrust centers as nearly in line as possible. The final configuration resulted in lowering the horsepower requirements from the preliminary model of 45 hp to 30 hp due to reduction in drag.

Studies were also conducted on thruster and propeller sizes. It was decided to use six interchangeable thrusters (two in the vertical and four in the horizontal) to provide maximum repair flexibility and minimum purchase costs. This resulted in a power requirement of 5 hp per thruster; off-the-shelf thrusters in this power range operate most efficiently at approximately 1000 RPM. Sixteen-inch propellers with thrust-augmenting shrouds were found to be most efficient. The final configuration reached after these studies produced drag forces shown in Figure 10. Final power versus drag calculations show the NP is capable of maintaining 5 fps horizontal speed. Results from the simulation study show this speed to be adequate for the expected SRB motions

Material Selection

A materials study determined critical design parameters for the NP structural components and evaluated candidate structural materials using the following criteria:

- Corrosion resistance
- Cost
- Availability
- Ease of fabrication
- Strength
- Weight
- Reliability

On the basis of weight and corrosion considerations, the aluminum alloys offered the best characteristics. Of the aluminum alloys, the 5086 series was selected as providing the best service in the expected marine environment. Wherever dissimilar metals are used, nonconducting material such as nylatron is used to prevent galvanic action.

Dewatering System Study

Two methods for dewatering the SRB were studied: mechanically pumping water out of the SRB or forcing water out by injecting air into the SRB. Analysis showed that to dewater the SRB within the required time (three hours) would require pump capacities greater than any available off-the-shelf pump. Since air must be supplied to the SRB as water is pumped out, no simplification in the dewatering system would result by using the pump, and special development efforts would be required. Forcing air into the SRB is a reliable system with all required components readily available and with known performance characteristics.

Failure Modes and Effects Analysis (FMEA)

The purpose of an FMEA is to identify points of failure and their effect on system performance and to permit their reduction or elimination when possible. The analysis covers all electronic, hydraulic, and pneumatic elements of the system.

The philosophy of this analysis is to conduct it in an iterative manner. Each iteration of the analysis proceeds through three basic phases. First, the mission profile for a typical SRB Dewatering System mission is defined and examined. Each part of the mission is defined and described. The preliminary analysis resulted in the following general mission profile:

- Prelaunch checkout
- Launch

- Postlaunch checkout
- Transit and navigation
- SRB inspection
- NP docking
- Dewatering
- Sealing
- Umbilical disconnection
- Towing
- NP removal
- NP refurbishment

As the system design is refined, the mission profile will be updated. During the second phase of the analysis, a reliability block diagram is prepared for each of the parts of the mission profile. The reliability block diagram graphically illustrates the reliability-oriented, series-parallel relationships of the elements of the design. Once the failure modes are determined, the third phase of the analysis begins. The failure modes of each element of each reliability block diagram are analyzed and the effects of these modes on system performance, launch and mission success, are evaluated. The relative probability of occurrence of each failure mode is then calculated based on failure rate and mode data from a variety of sources. The probability of success of each phase of the mission profile is then calculated.

As each iteration is completed, the results are provided to the engineering team, along with recommendations as to where design trade-offs can be accomplished to eliminate or reduce points of failure.

SYSTEM CONFIGURATION

During the early stages of design, it was determined that the SRB Dewatering System would be divided into two major subsystems: Shipboard Support, which consists of a control console, compressed air supply, and power supplies, and the NP. The umbilical cable was then selected to provide the necessary mechanical, pneumatic, power and electrical interface between the Shipboard Support and the NP. A major consideration in the design of all portions of the SRB Dewatering System was the use of existing off-the-shelf technology.

Shipboard Support

Control Console. Functional areas were determined for the control console: thruster control, navigation, NP status, and dewatering. See Figure 11 for the block diagram of the control console. Human factors engineering was used to divide the four

functions between an upright console and a table board (Figure 12). Navigation and NP status displays, as well as the video monitor, are grouped on the upright console. All controls (thruster, dewatering, and video camera tilt and focus) are located on the table board, within easy reach of the operator. Also on the table board are the mission-critical displays of docking and locking arm deployment lights.

The thruster control consists of a two-axis joystick for horizontal control with a rotational control knob on top and a separate vertical control stick. Joystick control is proportional in both speed and direction. When the control is moved in a given direction, the NP responds to the movement in the same direction and the speed of movement is proportional to the distance the joystick is moved. Vertical thrust control is also proportional to the movement of the vertical control with a forward movement translated as an upward thrust.

Navigational functions include depth and heading displays as well as the video displays and controls. Except for the video tilt and focus controls, located on the table, all navigation functions are grouped on the upright console. Depth is displayed in a digital readout (feet) and heading display uses both a digital readout to the nearest degree and a LED compass rose display to the nearest 100. Buffering circuits for the LED display average the heading over short time periods in order to present the operator with a more easily observed display. The tilt and focus controls for the video camera are located on the table with the NP controls and the tilt display is on the upright console with the other displays. As with the vertical thruster control, a forward movement of the video tilt control tilts the camera up and a forward movement of the video focus control focuses the camera on a point farther from the NP.

The NP status group consists of a leak detector display and power and hydraulic condition displays. In order to reduce the number of displays, each meter is used to monitor separate, but similar functions, depending on the setting of a control switch directly below each meter. Both 440 VAC and 120 VAC are monitored on one meter. The hydraulic pressure from either of two electro-hydraulic power units are monitored on a second meter and either hydraulic volume or fluid temperature are monitored on a third meter. Leak detectors are placed in various parts of the NP. A single display light illuminates if there is salt water present in the closed system.

The dewatering group consists of displays and controls critical to the dewatering mission of the NP. These are grouped on the table with the NP controls. When each leg is firmly positioned in the SRB, sensors on the four legs provide a signal which illuminates the docking displays on the control console. The center light in this display group illuminates when all three locking arms are deployed and locked. Dewatering group controls consist of locking arm deployment, sewer plug bag inflation, dewatering air control, and dewatering hose release. All four controls are grouped together on the left of the table and are protected by individual switch guards to prevent accidental activation.

Compressed Air and Power Supplies. Compressed air for dewatering is supplied from the support ship. Compressed air for inflating the sewer plug is carried on board the NP in high-pressure storage bottles. Power supply for the Dewatering System is 120 and 440 V, 3-phase, AC supplied by the support ship.

Nozzle Plug

NP design (Figure 13) was based on the mission requirements and the availability of off-the-shelf hardware and technology. Preliminary simulation modeling, hydrodynamic studies, material selection trade-off, and the development of a dewatering system were used to develop the NP configuration and power requirements. Once the over-all package concept was established, seven functional areas were considered in the design (Figures 14a and 14b).

- Structure
- Power and Control
- Hydraulics and Thrusters
- Dewatering
- Video
- NP Sensors
- Search and Recovery (SAR)

Structure. Series 5086 aluminum was chosen for the basic framework. Housings for the hydraulics, electronics and compressed air supplies are modular for ease of maintenance and the structure and internal mountings were designed to withstand shocks and stresses from over-the-side deployment of the NP. Built into the framework is a shock mitigation system (Figure 15) that allows the NP to provide automatic corrections for variations in nozzle lining thickness due to lining burnout and to absorb any shocks during the docking maneuver.

Power and Control Group. Power and control functions include the umbilical interface, power conditioning and distribution, power monitoring, signal conditioning and transmission, and control and buffering circuits. All electrical power enters the NP through the Power Control Group and commands and data signals between the control console and the NP are processed within this group.

Hydraulic Group. Figure 16 is a block diagram of the hydraulic system within the NP. Two electro-hydraulic units provide 15 hp of hydraulic power each. A normally closed valve isolates the two units, preventing momentary fluid starvation if all thrusters are simultaneously put to full power, but, when opened, allowing either electro-hydraulic unit to power all hydraulically operated units. Thrusters are bent-axis piston type, chosen for their excellent control at low speeds, light weight, and reliability. Hydraulic cylinders for the control of the locking arms and video tilt unit are standard off-the-shelf items.

Dewatering Group. The dewatering group consists of docking and locking arm deployment sensors, locking arms, pneumatic controls for inflating the sewer plug and providing air for dewatering, a sewer plug and a dewatering hose. When the NP is properly docked within the SRB nozzle, sensors in the NP structure provide input signals to the control console, illuminating the docking display lights. When all four lights are on, the operator is assured of a solid docking and can then deploy the locking arms. If all three arms are properly deployed and locked, a light indicates the NP is firmly in place and initial dewatering of the SRB can start.

The three locking arms are pictorially shown in Figure 17 and are hydraulically operated, over-center locking devices used to hold the NP firmly in place inside the nozzle. Once deployed and locked, the arms provide a solid mechanical lock between the NP and the SRB. If necessary, the arms can be unlocked and relocked from the control console.

With the NP docked and locking arms deployed, initial dewatering is started. Air from a compressor onboard the support vessel is fed, via the pneumatic hose married to the umbilical cable, into the SRB casing, forcing water out until the SRB assumes the log mode.

The sewer plug is then inflated to seal the nozzle. An electro-servo valve controls the flow of compressed air from a cylinder onboard the NP and on command from the control console, the valve opens and compressed air inflates the sewer plug.

The sewer plug is an inflatable rubber toroid mounted on a central mandrel. It is constructed of well-tested and fuel-resistant material in current commercial production with a minimum life of ten missions. It is designed to be self-storing so that special packaging procedures will not be required.

After the sewer plug is inflated and the SRB nozzle sealed, final log mode dewatering is accomplished by building up pressure within the SRB and forcing the remaining water out through a dewatering hose. When the operator presses the dewatering hose release control, the solenoid releases a latch and the dewatering hose deploys. The hose is weighted and mounted to a 360° swivel plate, allowing the hose to automatically fall to the lowest part of the SRB, insuring complete dewatering.

Video Group. The video group, which provides the operator with visual controls during recovery operations, consists of an underwater, silicon diode video camera with a quartz iodide light, and a hydraulic tilt unit with a tilt position sensor. Both the light and camera can operate in either air or water. The video camera is equipped with an automatic iris control which maintains proper exposure. The camera also has a remote focusing system which responds to command signals from the control console to correctly focus the camera. The tilt unit is a standard off-the-shelf item and the position sensor is a potentiometer mechanically attached to the tilt mount.

NP Sensors Group. The NP sensors group consists of a compass, a depthometer, and leak detectors. The compass is a production model magnetic compass. The sending unit converts angular displacement into a pulse train where each pulse represents one degree of rotation from magnetic north. The depthometer is also a standard production model and consists of a potentiometer attached to a pressure diaphragm. Leak detectors installed at various points within the NP detect salt water by the proven method of grounding the circuit when salt water is present.

Search and Recovery (SAR) Group. In the event the NP becomes disabled or lost, means have been provided to aid in its location. An underwater acoustic locating device provides sonar contacts during search operations. Should the umbilical become severed and the NP lost, a radio beam and a flashing strobe light will provide means for visual contact.

UMBILICAL CABLE

The 600-foot Umbilical Cable has an integral kevlar strength member of 10,000 pounds and an outer scuff jacket. The pneumatic hose is married to the cable and floats are attached during launch.

MODULAR APPROACH

The NP utilizes the modular philosophy (Figure 18). In the event that future modifications are required to the NP to accommodate SRB retrievals, they can be accomplished at minimum cost and design change. In addition, the modular concept enhances maintainability.

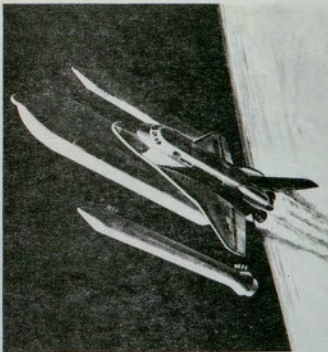


Figure 1. NASA Space Shuttle.

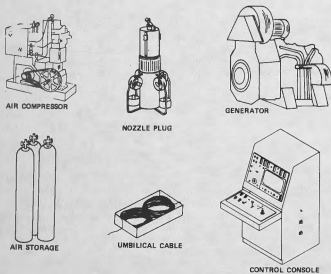


Figure 2. SRB Dewatering System.

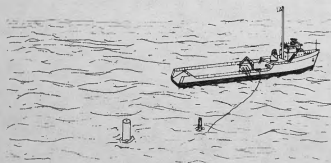


Figure 3. NP Transit to SRB.

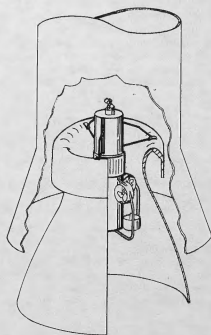


Figure 5. NP Docked.

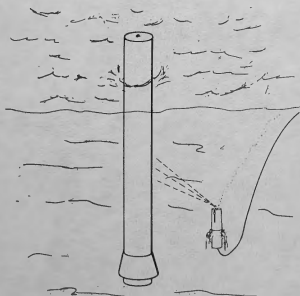


Figure 4. Inspection of SRB.

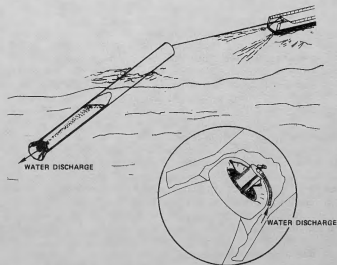


Figure 6. Log Mode Dewatering.

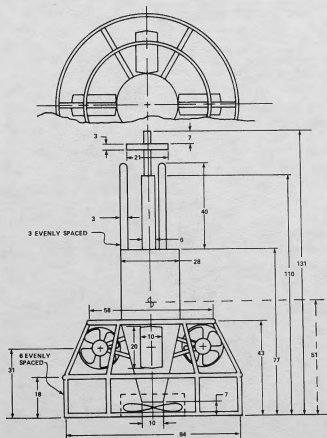


Figure 7. Preliminary NP Configuration.

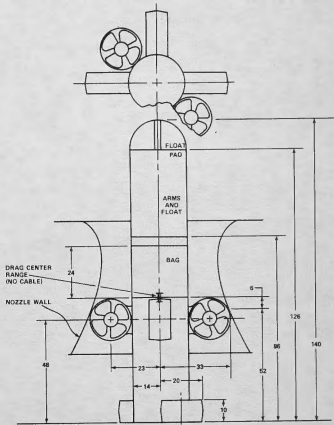


Figure 9. Final NP Configuration.

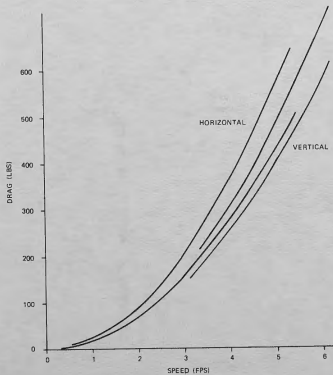


Figure 8. Preliminary NP Configuration Drag.

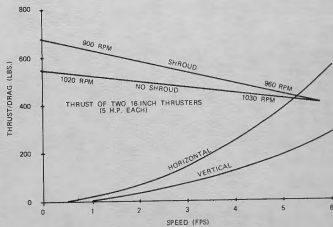


Figure 10. Final NP Configuration Drag and Thrust Curves.

SHIPBOARD

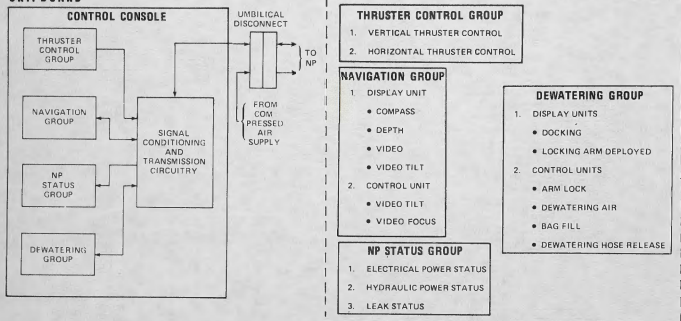


Figure 11. SRB Dewatering System Functional Block Diagram (Shipboard).

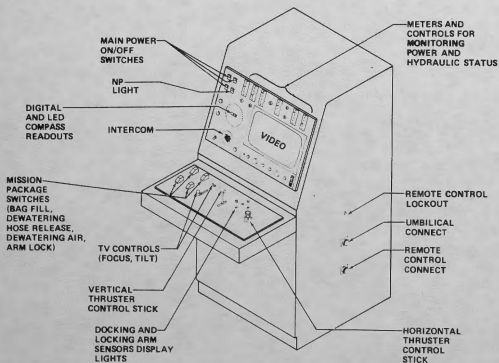


Figure 12. Control Console.

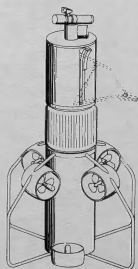


Figure 13. SRB Dewatering System Nozzle Plug.

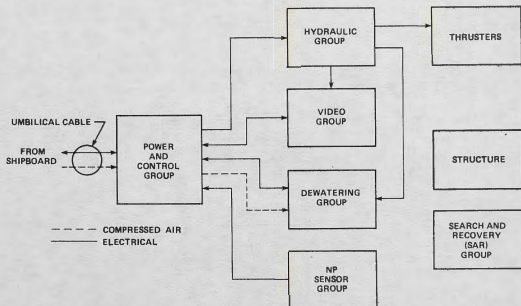


Figure 14a. SRB Dewatering Functional Block Diagram (NP).

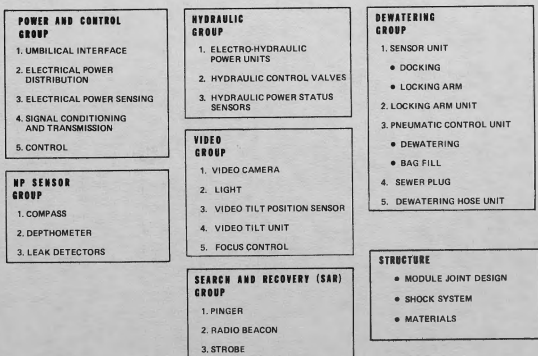


Figure 14b. SRB Dewatering System Functional Block Diagram (NP).

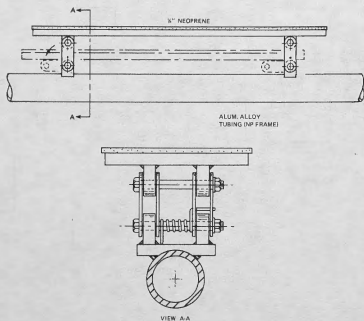


Figure 15. NP Shock Mitigation System.

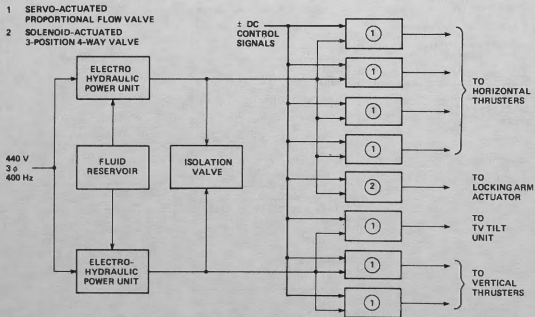


Figure 16. Hydraulic Functional Block Diagram.

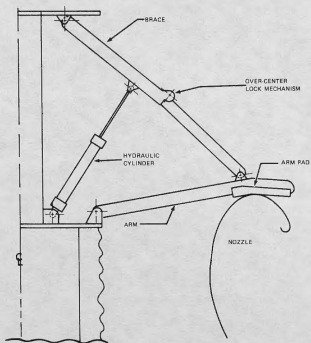


Figure 17. Locking Arms
Pictorial Presentation

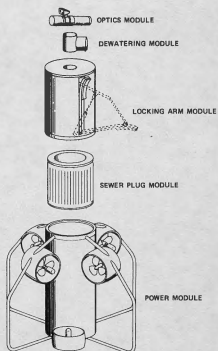


Figure 18. NP Modules.