SHUTTLE HITCHHIKER EXPERIMENT LAUNCHER SYSTEM (SHELS)

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ABSTRACT

NASA's Goddard Space Flight Center Shuttle Small Payloads Project (SSPP), in partnership with the United States Air Force and NASA's Explorer Program, is developing a Shuttle based launch system called SHELS (Shuttle Hitchhiker Experiment Launcher System), which shall be capable of launching up to a 400 pound spacecraft from the Shuttle cargo bay. SHELS consists of a Marman band clamp push-plate ejection system mounted to a launch structure; the launch structure is mounted to one Orbiter sidewall adapter beam. Avionics mounted to the adapter beam will interface with Orbiter electrical services and provide optional umbilical services and ejection circuitry. SHELS provides an array of manifesting possibilities to a wide range of satellites.

INTRODUCTION

In 1984, the NASA Headquarters Office of Space Flight (OSF) established the Shuttle Small Payloads Project (SSPP) at the Goddard Space Flight Center to develop and operate carrier systems for low-cost and quick reaction accommodations of secondary payloads on the NASA Space Transportation System (STS). These carrier systems range from the more complex such as the Hitchhiker (HH) carrier system to the self-contained Get Away Special (GAS) carrier system. To date, SSPP has flown over 285 cargo-bay payloads aboard the Space Shuttle.

Utilizing modular hardware components, HH payloads may vary in weight and size from a few hundred pounds up to 5500 pounds; the former requiring the mounting provisions of a single adapter beam and the latter requiring a full cross-bay bridge. HH payloads use Orbiter power and data services and provide experimenters with real-time command and telemetry link to a control center located at Goddard.

Over the years, SSPP has developed adjunct systems to the HH carrier providing additional accommodations and manifesting possibilities to a wide variety of Orbiter users. The recently developed Hitchhiker-Jr. Carrier system, using a Hitchhiker Remote Interface Unit (HRIU) in a single five-cubic-foot canister, receives Orbiter power and is commanded by and sends telemetry to the crew controlled Payload General Support Computer (PGSC) laptop. Additionally, SSPP has developed a small launcher system capable of ejecting 150-pound satellites (or other experiments) from either a canister or a cross-bay bridge pallet.

More recently, SSPP has begun development of the SHELS launcher system. Both the NASA Explorer Program Office and the U.S. Air Force Space Test Program (STP) Office are funding the SHELS development effort. SHELS shall be capable of ejecting up to a 400-pound spacecraft and will provide the option of power and data umbilical services. The Explorer Program Office wants a launch system provided that is compatible with its University Explorer (UNEX) class missions while the U.S. Air Force STP Office has targeted SHELS for a number of its small satellites. It is anticipated that other users will step forward as the SHELS system becomes operational sometime in the 2001 time frame.

SYSTEM OVERVIEW

Taking advantage of an array of existing modular components and Orbiter power and data services, the SHELS system development effort requires little in the way of new electrical hardware design. The bulk of the design effort is an ejection mechanism and launch structure. As shown in Figure 1, with existing hardware shaded, the SHELS system components include: the HH avionics and its mounting plate; the Hitchhiker Ejection System Electronics (HESE); the Satellite Interface Box (SIB); the SHELS support structure; and ejection system. For those spacecraft that do not require umbilical service, the SIB is not required.

As seen in Figure 2, the HH avionics provides the interface to Orbiter power and data services and crew controlled Standard Switch Panel (SSP) switches. For umbilical users, power and data command/telemetry signals are routed to the spacecraft via the HH avionics and SIB. The SIB provides signal isolation protection to the HH avionics circuitry. The SSP switches are routed via the HH avionics to the HESE, which contain the PRE-ARM, ARM, and FIRE relays. These relays and their status provide safety inhibit and monitor functions necessary to prevent accidental spacecraft ejection and other related hazards.

The SHELS launch structure is a monolithic investment cast structure, which is cast from A356-T6 strength class 10 aluminum alloy, and mounts directly to the sidewall adapter beam. The SHELS ejection system mounts to the top of the launch structure and uses a Marman band clamp mechanism approximately 17 inches in diameter. The ejection system push plate design accommodates the mounting of the umbilical power and signal connectors. The SHELS ejection dynamics do not impart any significant tip-off or rotation about the satellite's ejection axis. A mission unique thermal shroud will surround the payload and mount to the support structure.

With its ability to be mounted to the Orbiter sidewall, the SHELS design allows for ease of manifesting and requires little in the way of Orbiter resources.
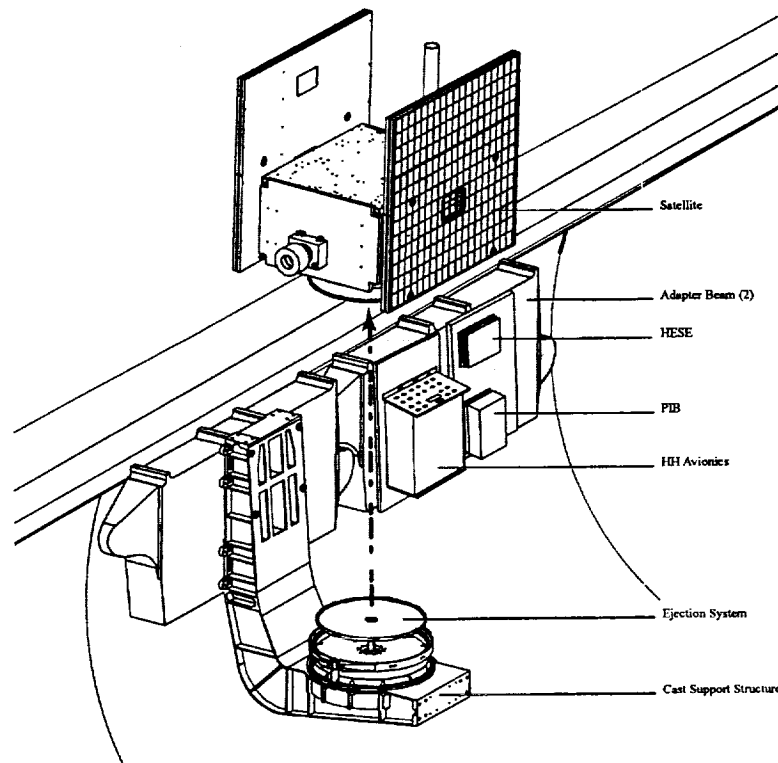

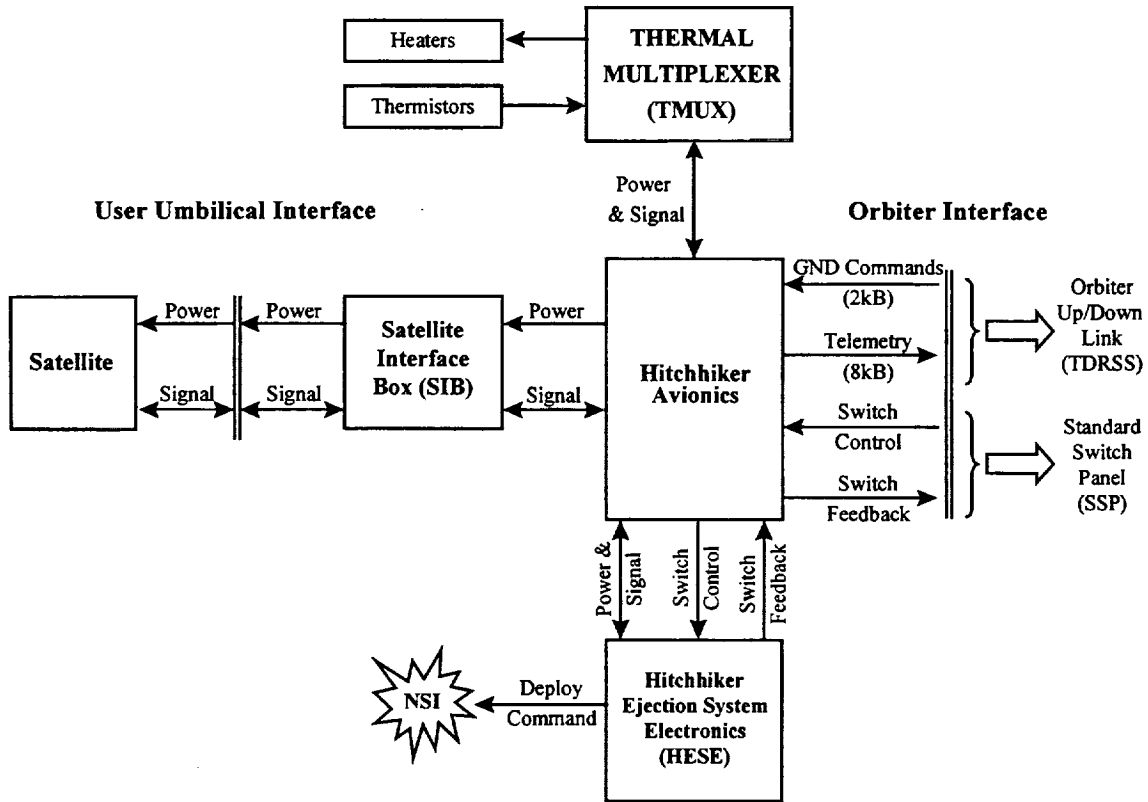**Figure 1. SHELS with Existing Hardware (Thermal Shroud Not Shown)**

Figure 2. SHELS Electrical Functional Block Diagram

ACCOMMODATIONS

The SHELS system is being designed to accommodate up to a 400-pound satellite with a center of gravity (CG) no more than 24 inches above the ejection system separation plane. The satellite CG must be within .25 inches of the ejection system centerline.

While the structure must meet all load and frequency requirements of accommodating a 400-pound satellite with a 24-inch CG offset, what remains to be determined is the Orbiter capabilities of accommodating such loads. The weak link in the SHELS system is the three bolts that attach the adapter beam to the Orbiter sidewall. It is expected that the Orbiter capability shall vary from one cargo bay location to another as the loading on these three bolts is highly dependant on the cargo bay payload complement. A coupled loads analysis to be run in '00 shall provide loads data that will determine actual SHELS system capabilities with respect to payload mass and CG.

Allowable satellite envelope is currently being defined; its constraints are driven by complex geometry. The payload envelope is constrained in the vertically (Orbiter Z axis) by the cargo bay door envelope. The payload envelope constraints in the X and Y axes are generally limited by the clearances between the payload and the cast structure and the payload and the thermal shroud. The largest rectangular-shaped satellite that would fit within the current payload envelope is 36 x 25 x 46 inches in the X, Y, and Z axes, respectively.

The ejection velocity is expected to be between 1.5 ft/sec and 4.0 ft/sec. There is no capability to spin-up a payload prior to ejection. The design shall preclude tip off rates that would result in colliding the payload with the thermal shroud; at this time there has been no analysis to determine a tip off rate.

Payload customers are required to withstand applied loads of 11 g's in the X, Y, and Z axes simultaneously with safety margins of 1.25 on yield and 1.4 on ultimate. These load factors are applied at the center of mass of the ejected payload.

Thermal shroud survival heaters shall supply a maximum of 280 Watts power at 28VDC. Heat is radiated to the payload.

The electrical umbilical shall provide a power and a signal interface connector to the payload. Total power available is 280 Watts at 28VDC divided among four circuits rated at 2.5 Amps maximum each. The signal interface shall provide 1200 baud asynchronous command and telemetry, three analog 0-5 volt signal inputs, three digital 28 Volt bi-level signals and a minute pulse.

MECHANICAL SYSTEMS OVERVIEW

The SHELS mechanical system consists of a launch structure, ejection system, and mission unique thermal shroud. The system is designed to accommodate a wide range of spacecraft and provide a cost effective user friendly launch system with minimum integration. The entire system is being modeled in Pro-Engineer™. Figure 3 shows a 3-D view of the SHELS launch structure and the ejection system.

Launch Structure

The SHELS launch structure is a premium quality, aerospace, structural casting with a riveted stress-skin panel for increased torsional capability. The casting material is aluminum alloy A356-T6 strength class 10, fabricated with rapid prototype casting techniques. Investment castings traditionally have been fabricated by the lost wax method, requiring tooling to produce an injection molded, near net shape, wax pattern. Once produced, the wax patterns are processed by bonding preformed wax gates and risers to facilitate casting. Then the pattern is invested, or dropped, in a stucco solution of fractured ceramic and water. The stucco encapsulates the entire wax pattern with ceramic approximately .25 inch thick per side producing a casting shell. The shell is dried at room temperature then heated or de-waxed in an autoclave in order to melt and pour off the wax from within the shell. Hence the term lost wax method. The shell is then fired in a furnace and filled with the desired molten alloy. When the casting cools and solidifies the shell is broken away, the gates and risers are removed and finished. The casting is then annealed, straightened, solution treated to T6 condition, and inspected. The inspection process includes dimensional and non-destructive evaluation (liquid penetrant and x-ray).

The rapid prototype technique varies from the lost wax method by substituting a precision crafted wooden pattern for the wax pattern. The wooden pattern is then gated, invested, dried, and burned out in a furnace at the ignition temperature of the wood. After pattern burnout, the shell is cooled, flushed, and inspected to insure that the shell is free of debris. The shell is then processed in the same manner as a traditional investment casting.

The rapid prototype casting method may appear labor intensive but the wooden patterns are produced direct from a solid CAD-CAM model and routed to shape by CNC routers and conventional woodworking techniques. The routed sections are then assembled, filleted, and inspected to prepare them for foundry processing. This method foregoes the need for injection molding tools and provides engineers with incredibly complex structures priced competitively with conventional structures at quantities of one.

Goddard has successfully developed and flown numerous structural castings and one satellite that was entirely investment cast. The castings have proven cost and weight efficient and structurally robust. Cast structures provide 100% joint efficiency and allow designers to produce complex and compact structures previously inaccessible or incapable of fabrication by welding, riveting, or machining. This advantage allows designers to selectively localize material at key structural points and use cross-sectional inertias to their maximum advantage. In addition, high efficiency structural forms previously costly to fabricate, such as isogrid and geodesically stiffened lattice, become cost competitive when cast.

Castings offer an additional cost advantage by reducing designing, drafting, and checking. Fewer parts translate directly to project savings.
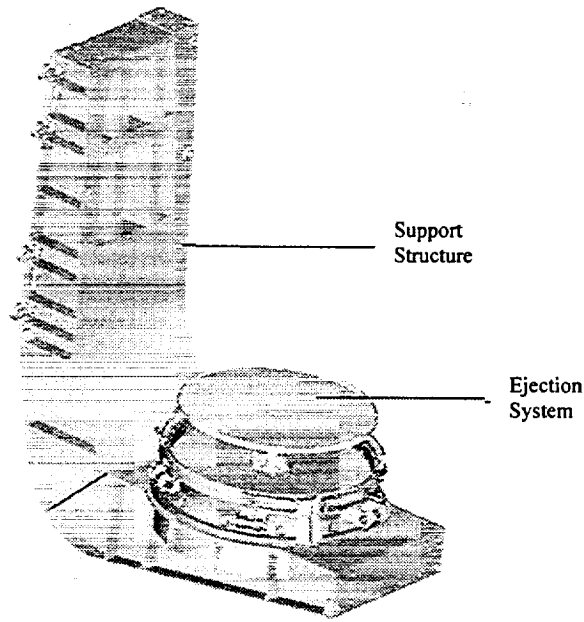
Support
Structure

Ejection
System

Figure 3. Cast Aluminum Structure in 3D

Ejection System

The SHELS ejection system consists of a strap and shoe Marman band, ejection base and center mounted compression spring/push plate assembly. The thermally isolated ejection system is mounted to the SHELS launch structure, which provides the structural interface to the adapter beam.

The Marman band consists of two stainless steel tension straps and ten shoes which are loosely riveted to the strap. Trunnions are riveted to the ends of each strap and provide a swiveled attach point for the separation bolts which tension the system. The aluminum and titanium shoes have 20° ramp angles and low friction hard coatings applied to all surfaces. The titanium shoes are located under each of the end trunnions due to the higher local loads produced at these locations. When the separation bolts are preloaded, the shoes clamp the system by riding up matching ramps on the ejection base flange and payload interface plate flange. Each of the separation bolts will also have a bolt force sensor to monitor band tension during assembly, testing, and under various environmental conditions. The Marman band will be pull tested to worst case conditions to verify no gapping occurs at the interface. A 1.25 test factor will be used.

The Marman band is released by redundant, NSI actuated, bolt cutters. A nominal separation of the payload from the ejection base will occur if only one of the bolt cutters functions. When the separation bolts are cut, the Marman band snaps off the flange interfaces and is held in a retracted position by six torsion spring assemblies. Once the Marman band has snapped off the flanges, a centrally located compression spring is free to push the payload away from the ejection base. A guide shaft riding in a set of linear ball bearings guides the push plate during the stroke of the spring. The linear bearings provide a low friction, tightly controlled ejection with low tip off imparted to the payload. A line of balls in each linear bearing also rides in a "V" groove cut down the length of the guide shaft. This arrangement prevents the spring from imparting a rotational input into the payload during ejection. Ejection velocity may be tailored to the payload requirements by placing different size compression springs in the adjustable spring housing. Presently the maximum ejection velocity for a 400-pound payload is 4 ft/sec with a maximum 5 in stroke.

As an optional capability, the ejection system allows for the mounting of two internal or two external low force umbilical connectors. The connectors provide power and telemetry to the payload while it is in the Orbiter bay prior

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to ejection. The two internal umbilical connectors would be mounted on adjustable brackets on the ejection base plate right next to the compression spring assembly. The two external umbilical connectors would be mounted to brackets attached to the outside diameter of the ejection base.

Electrical Systems

The flight electrical segment provides the interface with the Orbiter for power, command and telemetry, both ground and crew. The electrical system is illustrated in Figure 2.

Functional Overview

For a typical mission, shortly after orbit insertion, the crew will activate the HH avionics from the SSP. Once activated, command (2 Kbps) and telemetry (8 Kbps) processing is controlled from the Advanced Carrier Customer Equipment Support System (ACCESS) located in the Payload Operations and Control Center (POCC) at Goddard. Communication of the commands and telemetry occurs through the Tracking and Data Relay Satellite System (TDRSS) and associated ground network.

The initial setup of the HH avionics includes health checks, survival heater activation, and then experiment power on, as necessary. As the deployment window approaches, the satellite will be deactivated. Then the HESE will be activated via ground commanding and operated by the crew to deploy the satellite. Once deployed, satellite commanding will be conducted from the experimenter's ground station.

At mission's end, the HH avionics power distribution system is deactivated from the ground, then the crew will deactivate the HH avionics from the SSP in preparation for the return home.

Carrier Electrical Description

The HH avionics interfaces to the Orbiter to provide electrical services to the experiments. These services include: hardwire switching and displays to the HESE electronics for satellite deployment, real-time command (uplink at 2 Kbps) and telemetry (downlink at 8 Kbps), and electrical power distribution. For SHELS, the satellite power interface will be limited to 280W.

The thermal multiplexer (TMUX) acts as a power distribution unit. It uses a single avionics power port and distributes up to 400W to multiple, thermostatically-controlled heater circuits. The TMUX multiplexes the local heater circuit temperature data, monitored by thermistors, for transport to the ground processing system.

The SIB is used to isolate the satellite from the HH avionics. The SIB uses one power and signal port on the avionics to interface with the satellite. Side A of the power port (280W) is fused and diode isolated from the avionics power system. Side B is used to power the signal isolation interface electronics located in the SIB. The isolated signal interfaces currently identified are 1200 baud asynchronous command and telemetry, three 0-5 V Analog telemetry inputs, three +28V bi-level / pulse outputs, and one Mission Elapsed Time Minute pulse (METMIN) output.

The umbilical interface is only required by an experimenter who wishes to use the power/signal interface with the HH avionics. This interface design uses the NEA Electronics™ proprietary 'soft' release connector technology at the satellite interface to the ejection system. Currently there are two umbilical connectors located within the ejection system pedestal assembly. One connector is primarily dedicated to power, the other is dedicated to signal.

HESE provides the required number of (safety) inhibits and controls to prevent inadvertent satellite deployment. The crew uses three switches on the SSP to sequence the HESE through the deployment sequence. The HESE is only powered during the deployment sequence.

Two NASA Standard Initiators (NSI), each with a booster cartridge, are integrated into two HH-designed bolt cutter assemblies. These bolt cutters sever two bolts to release the Marman band clamping the satellite to the ejection system structure. The function of the NSI's is achieved through the operation of the HESE.

Advanced Carrier Customer Equipment Support System (ACCESS) (not shown) provides the ground data handling between the customer's ground hardware and the Orbiter data network.

Thermal Systems

The thermal design of the SHELS casting and ejection system shall be consistent from mission to mission. This design is passive and is composed of various surface finishes including multi-layer insulation (MLI).

The thermal design of the shroud shall vary from mission to mission and be driven by the particular thermal requirements of the satellite. The maximum thermostatically controlled heater power available to the shroud is 280W. Other passive thermal controls shall vary on a case-by-case basis.

The MLI shall incorporate alternating layers of Kapton™ and Dacron™ netting with an outer layer of beta cloth for durability.

The casting shall be directly mounted to the Adapter beam allowing the casting to closely follow the temperature of the beam. By mounting this way, the thermal stresses induced in the casting shall be reduced. Conversely, the ejection system and satellite shall be isolated from the casting to the maximum extent possible. MLI shall be attached to the thermal shroud as necessary to maintain the satellite at its safety and non-operational limits and to decrease the amount of shroud heater power loss.

To qualify the design, the casting and ejection system shall go through thermal vacuum testing.

A geometric model shall b developed using VIEW 386 and SSPTA 386. A thermal math model shall be developed in SINDA85.

STRUCTURAL VERIFICATION

Analysis

A finite element model of the SHELS launch structure has been created for static and dynamic analysis. The pre and post processor used for creation of the model and visualization of the results is FEMAP, version 5.0, a product of Enterprise Software Products, Inc. The finite element solver used for static and normal modes analysis is UAI/NASTRAN, version 20, a product of Universal Analytics, Inc.

The quasi-static design loads used for analysis are 11 g's applied simultaneously in three orthogonal axes. All positive/negative combinations are evaluated, for a total of eight load cases. The design loads are based on the loads used for traditional HH payloads mounted to the Orbiter sidewall. The design case is a payload that weighs 400 pounds and has a CG 24 inches above the separation plane. Detailed stress analysis is ongoing.

Several iterations were made in the design of the launch structure to increase its stiffness and raise the fundamental frequency. Through experience with other sidewall mounted payloads, it was determined that the frequency should be well above 21 Hz, if possible, to avoid excessively high loads that could result from certain landing forcing functions in the coupled loads analysis. The final design of the launch structure has a fundamental frequency of 29 Hz. Plots of the first two mode shapes are shown in Figures 4 and 5. The finite element model of the support structure will be coupled with a model of the adapter beam for assessment of the stresses in the adapter beam. The adapter beam has previously been qualified to carry two 400-pound canisters. The analysis will determine whether any additional qualification testing will be required for the adapter beam.

A preliminary coupled loads study will be performed using the all-up SHELS math model, which will consist of the math models of the launch structure and the adapter beam, with a lumped mass representing the payload. This preliminary study will give an indication of the expected loads and interface forces. The study will use the current Orbiter math model and forcing functions.

Updated Orbiter math model and forcing functions are currently being developed. A significant reduction in the loads predictions for sidewall payloads is anticipated with the update. Therefore, a complete coupled loads analysis of SHELS in every potential Orbiter bay location will be performed after the release of the updated Orbiter model. This analysis will determine payload manifesting options by establishing payload weight and CG envelopes for each Orbiter bay location.

Testing

The SHELS launch structure, including the ejection system, will be qualified through a series of structural tests. Testing will include modal survey, static loads, random vibration, and functional and gravity negation.

Modal Survey

A modal survey will be performed for verification of the math model. The test configuration will consist of the SHELS launch structure attached to a representation of the adapter beam interface. The ejection system and a mass mockup of the payload will be attached to the support structure. All major structural modes below 50 Hz will be identified. The math model will be correlated with the frequencies and mode shapes measured in the test. Payloads shall have a fundamental frequency of at least 50 Hz or a modal survey will be necessary for the payload.
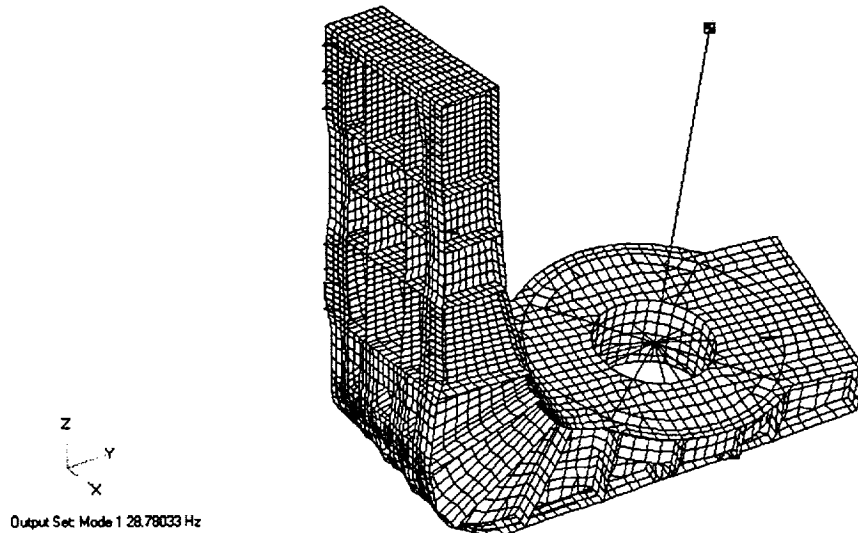
Z

Y

X

Output Set Mode 1 28.78033 Hz

Figure 4. SELS Launch Structure — Mode 1
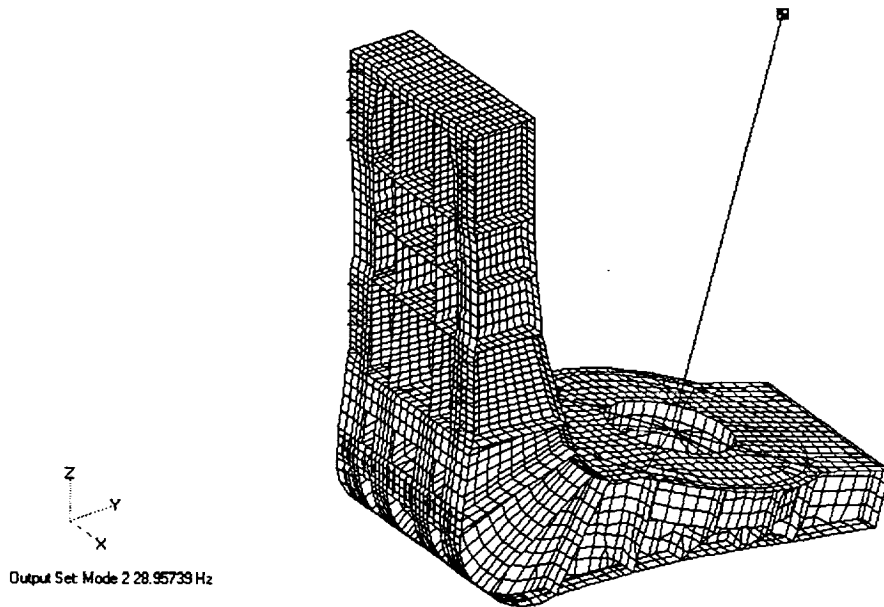
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Output Set: Mode 2 28.95739 Hz

Figure 5. SHELS Launch Structure — Mode 2

Static Loads Testing

A static loads test will be performed for strength qualification of the SHELS launch structure. Qualification of the launch structure and of the ejection system will be accomplished simultaneously. The load vectors for the test will be determined analytically. A test factor of 1.25 will be applied to the design loads.

The static loads test will consist of a series of three pull tests applying combined axial, shear, and moment loads to the Marman band interface. Marman band preload will differ for each pull test to account for the different mass properties (weight and CG) of future satellites. Data from these tests will validate the friction and stiffness parameters used in the basic Marman band preload equations. Successful completion of these tests will allow the specific mass properties of each payload and the predicted accelerations for that mission to determine band preload. A lighter payload, for example, can use a lower band preload, which decreases shock loading during band separation

Random Vibration Testing

Random vibration testing will be performed on the ejection system to qualify the design. The system will be subjected to random vibration in all three axes. The test input levels will envelope the maximum expected flight levels plus 3 dB and the recommended minimum workmanship levels. The maximum expected flight levels will be determined from a random base drive analysis.

Functional & Gravity Negation Testing

A large number of functional tests are planned for the ejection system to assure that the band will release from the interface flanges under varying conditions and system configurations. Several functional tests, including functional tests after each pull test, are planned: they will use different separation bolt preloads; single and double bolt cutter firings; and hot and cold temperature extremes. Some functional test will include the low force separation connectors. Gravity negation tests will also be performed to determine the amount of rotational tip off imparted to the payload by the ejection system during separation. The test will be performed with a payload mass simulator that

has been connected with cables over a set of pulleys to a counter weight that balances the system. The cable is connected to the mass simulator at a very low-friction ball joint that is positioned at the CG of the simulator. The low-friction ball joint allows the mass simulator to rotate when external load is applied to the system as if it were in a zero-gravity environment. A series of tests will be performed with varied conditions and configurations to determine worst case tip off rotations. These tests will help to establish design criteria for the thermal shroud and provide important information to payload attitude control systems.

FUTURE ENHANCEMENTS

To increase SHELS manifesting possibilities, it is advantageous to reduce SHELS from a two-beam configuration to a one-beam configuration as shown in Figure 6 and further minimize need for Orbiter services.

By expanding the functionality of the SIB, replacing the HH avionics with a single PGSC crew controlled HRIU, and adding two additional mounting plates to the SHELS casting adapter beam, it is possible to package SHELS on one adapter beam (Figure 7). Umbilical power and data services are now maintained via the PGSC, HRIU expanded SIB [Multipurpose Interface Box (MPIB)] configuration.

This new SHELS configuration eliminates Orbiter services required of a ground controlled payload. This configuration also enables the crew to power SHELS components, survival thermal shroud heaters not withstanding, just before satellite ejection, further reducing the need for Orbiter power services.
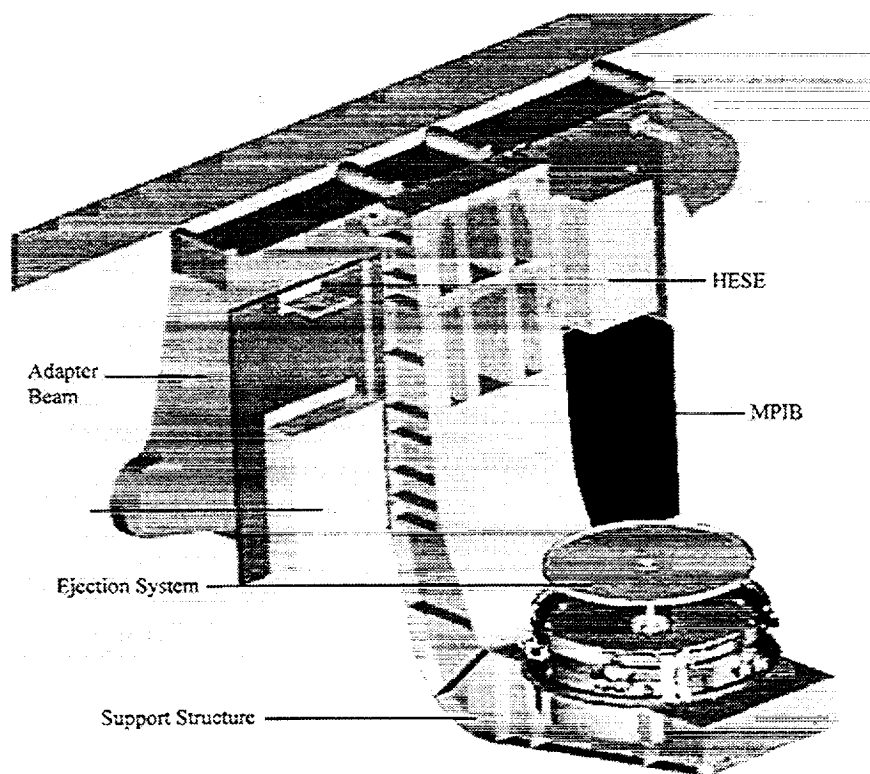

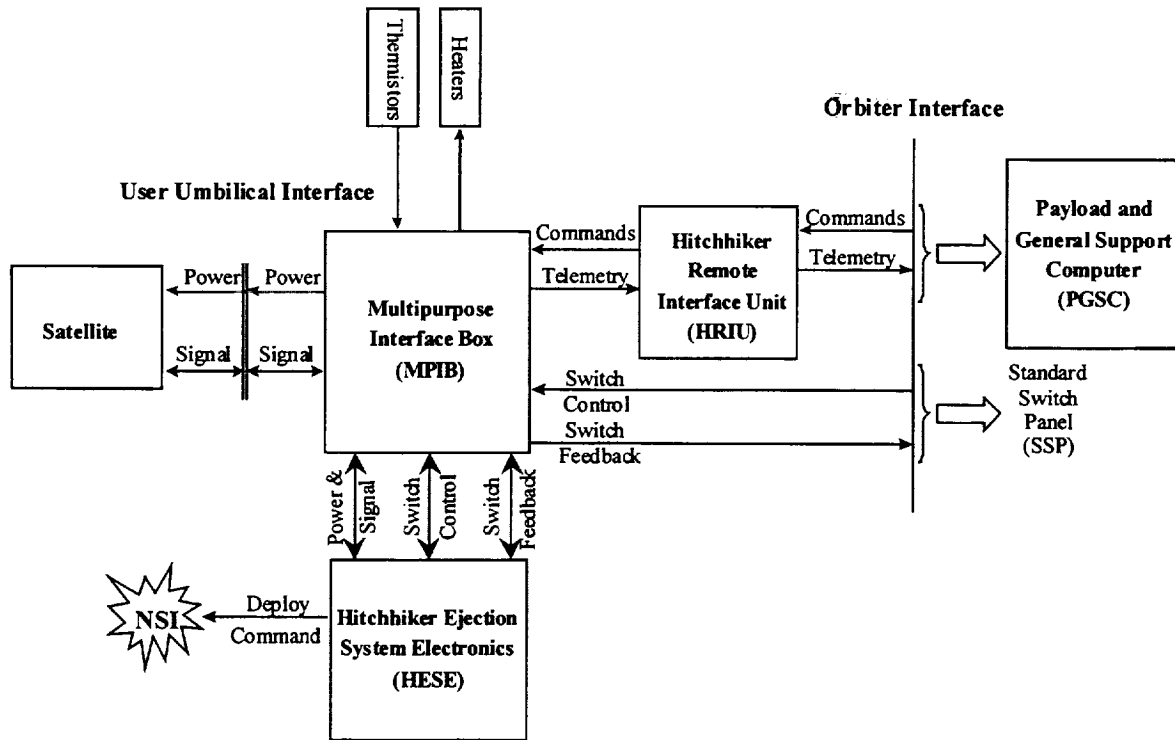Figure 6. SHELS Configured for One Sidewall Adapter Beam

Figure 7. SHELS Electrical Functional Block Diagram for One Sidewall Adapter Beam