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DESIGN AND FLIGHT TESTING OF AN INFLATABLE SUNSHIELD FOR THE NGST

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ABSTRACT

The Next Generation Space Telescope (NGST) mission is scheduled to launch in 2007 and be stationed at L2 for a mission life of ten years. The large aperture mirror and optical detectors aboard NGST require shielding from the constant solar energy seen at this orbit. The government reference NGST design, called the Yardstick, baselined a sunshield using an inflation deployment system.

During the formulation phase, NGST is spending approximately 25% of the overall budget to foster the development of new technology. The goal is to develop and demonstrate enabling or enhancing technology and provide innovative solutions for the design of the NGST observatory. Inflatable technology falls in the category of enhancing technology due to its advantages in weight, stowed volume and cost. The Inflatable Sunshield in Space (ISIS) flight experiment will provide a realistic space flight demonstration of an inflatable sunshield. The supporting technology development program will provide an information base for the design, manufacture, assembly and testing of large thin membranes and inflatable structural elements for space structures.

The ISIS experiment will demonstrate the feasibility of using inflatable technology to passively cool optical systems for NGST and provide correlation between analytical predictions and on orbit results. The experiment will be performed on a Hitchhiker/Space Shuttle mission in late 2001. The ISIS mission is an effort to address several major technical challenges of the NGST inflatable sunshield, namely controlled inflation deployment, planarity and separation of large stretched membranes, space rigidization of inflatable booms, and dynamic modeling and simulation. Success requirements for the mission are: the sunshield deploys and inflates as expected in a controlled manner; the sunshield withstands environmental loading after boom venting; measurements are obtained that characterize the shield deployment behavior; measurements are obtained that characterize the sunshield post deployment dynamics; and structural properties and measurements obtained during the mission validate the analytical model of the sunshield. As mission operations and design constraints permit, secondary mission measurements will be taken on membrane separation and flatness, structural interactions with the deployable mast and thermal performance of the sunshield.

The ISIS experiment is a sunshield that is one-third the size of the NGST sunshield. NASA-GSFC is partnering with ILC Dover, Inc. of Frederica, Delaware to provide the sunshield flight hardware for the experiment. The ISIS sunshield refers to all film layers, film management devices, booms, boom end tip assemblies, boom controlled deployment devices and rigidization systems. There are four booms on the sunshield of various lengths; the longest boom is approximately 17 feet long, another boom is approximately 14 feet long and the two remaining booms are approximately 6 feet long each. Each of the booms is comprised of an inflatable boom, a ladder assembly and a system to heat cure the boom. The inflatable boom is a thermoset composite

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material with an inside diameter of 5.125". The inflatable booms are pliable prior to curing the resin. This allows them to be flattened, rolled and stowed on a boom tip assembly cylinder attached to a ladder structure at the tip of the boom prior to inflation. The ladder structure provides separation of the membrane layers, 2.5-cm separation at the container interface and a 15.0-cm separation at the edge. When ISIS on-orbit operations commence, the booms are inflated with nitrogen gas at a low pressure (approximately 3.2psi). The booms unroll in a "party favor" fashion from the cylinder at the boom tip. A wire brake mechanism is used to control the rate of deployment. The controlled deployment device is located inside the cylinder at the tip of the boom. Once the booms have completely deployed, they are heated for approximately 45 minutes at $120^{0}C$ to cure the resin. The booms are then vented.

The sunshield is comprised of four membrane layers, made of reinforced Kapton VN, 0.0005" thick. The six inner membrane surfaces will be coated with 1000 Angstroms of Vacuum Deposited Aluminum (VDA), the outer two surfaces are bare kapton. A rip stop system is incorporated into the high stress areas of each layer to inhibit tear propagation of the membrane.

As the NGST observatory moves to map different parts of the sky, rotational and translational loads will be seen by the sunshield booms. The focus of testing the post-deployed ISIS sunshield will be the simulation of the predicted loads that the NGST observatory will encounter. Once the ISIS sunshield booms have been rigidized, the sunshield will be excited via Shuttle maneuvering that simulates NGST observatory movements. Data will be gathered from accelerometers and load cells to characterize the behavioral respose of the sunshield due to the excitation source. This data will enable the NGST dynamic models to be validated.

This paper will describe the design of the flight experiment and the testing to be performed on-orbit.

INTRODUCTION

The Next Generation Space Telescope (NGST) mission, the follow-up to the Hubble Space Telescope, is scheduled to launch in the 2009 time frame. NGST will be stationed at L2. The large aperture mirror and optical detectors aboard NGST require sun shielding from the constant solar energy seen at this orbit. The Goddard Space Flight Center (GSFC) yardstick-design of NGST baselines an inflatable sunshield for this purpose. Although inflatable structures have been demonstrated in space, the concept of controlled deployment has not been demonstrated in flight. The ISIS experiment will demonstrate the feasibility of using inflatable technology to passively cool optical systems for NGST and correlate structural data with analytical models. The experiment will be performed on a Hitchhiker Shuttle mission in late 2001.

Depending on its intended application, a space inflatable structure may fall into one of the two roughly defined groups: precision structures and non-precision structures. Precision inflatable structures refer mainly to telescope reflectors that operate in near infrared and optical wavelengths. These reflectors need to have very large apertures with highly precise configuration accuracy, usually in the micro or sub-micron range. The group of non-precision inflatable structures covers a much wider range of structural systems, including booms, beams, planer frames, and space trusses. The ISIS inflatable sunshield is an example of a non-precision inflatable structure, in which four inflatable booms are deployed by gas inflation. These booms, in turn, will deploy multiple layers of very large thermal membranes made of coated thin film. After deployment, the booms will be rigidized and vented. Rigidized booms must maintain their structural integrity for the entire mission life of ISIS. The rigidization method used for the ISIS mission entails heat curing of a thermoset composite that forms the structural system of each boom.

The ISIS mission is an effort to address several major technical challenges of an NGST inflatable sunshield, namely, controlled deployment of inflatable booms, space rigidization of inflatable booms, and dynamic modeling of inflatable structures and large, thin film membrane systems.

The ISIS mission test objectives are to demonstrate the feasibility of using inflatable technology to cool optical systems for NGST and correlate structural data with analytical predictions.

Mission success requirements are:

1. The sunshield deploys and inflates in a controlled manner.

2. The sunshield withstands environmental loading after boom rigidization and venting.

3. Measurements are obtained that characterize the sunshield deployment behavior.

4. Measurements are obtained that characterize the shield post-rigidized structural dynamics.

5. Measurements obtained during the mission validate the post-rigidized analytical model of the sunshield.

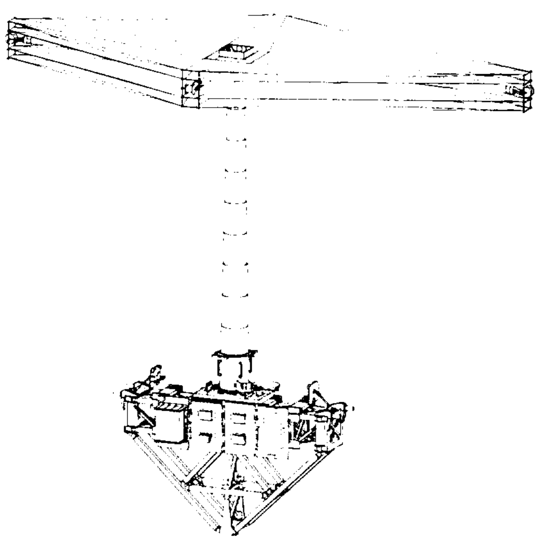

Figure 1: ISIS Deployed Configuration

Secondary mission measurements will be taken on thermal performance and structural interactions with the deployable mast. The in-flight measurements and technical data pertinent to the design, fabrication and assembly of the ISIS sunshield will also be made available to aid development of inflatable systems for future missions. The ISIS flight experiment is a Hitchhiker/Space Shuttle based mission designed to demonstrate inflatable technology and, more specifically, controlled deployment in space. The ISIS sunshield is approximately one-third the size of the NGST yardstick concept sunshield. It is comprised of four inflatable, rigidizable booms of various lengths and four thin-film Kapton membranes. The on-orbit configuration is shown in Figure 1. Before deployment, the booms and membranes are stowed in a sunshield container and held in place by a sunshield restraint and release mechanism. The stowed configuration is shown in Figure 2. The ISIS experiment is manifested on a

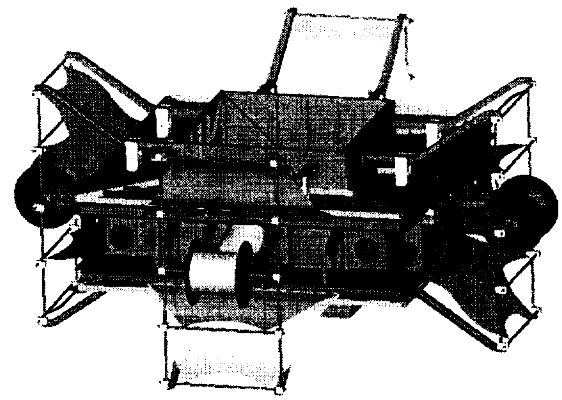

Figure 2: ISIS Stowed Configuration

Hitchhiker cross bay MPESS structure. Between the ISIS system and the Hitchhiker structure is a deployable mast to raise the ISIS system out of the shuttle bay prior to sunshield deployment. The sunshield is raised out of the shuttle bay to prevent sunshield recontact with the shuttle should the sunshield inadvertently buckle.

The current operational scenario begins with release of the stowed mast after the shuttle has achieved orbit. The mast is restrained with a Marman clamp. Once released, the telescoping mast raises the ISIS system 22 feet out of the shuttle bay. After the mast is fully deployed, the sunshield restraint is released and boom inflation can begin. A nitrogen gas inflation system delivers a 3.2-psi flow to the booms to inflate them at a rate of approximately 2 feet per minute. The short booms are inflated first followed by the long booms. Following inflation, the booms are heated to rigidize them. After the booms have rigidized, the shuttle performs a series of maneuvers to excite the sunshield. Accelerometers and force sensors record sunshield responses. When data acquisition is complete, the deployed sunshield and mast are released from the shuttle.

The design of the flight system and the flight-testing are discussed below.

MECHANICAL DESIGN

The mechanical system is divided into several subsystems. These subsystems are the inflatable booms, sunshield membranes, telescoping mast, sunshield container, boom and membrane launch restraint and release system, boom inflation system and sensors for recording sunshield dynamic responses.

Inflatable booms

The inflatable booms are designed and built by ILC Dover, Inc. Frederica, Delaware. The structural element of the booms after rigidization is a thermoset composite material. Prior to rigidization, the strength of the booms comes from the inflation pressure. The booms are required to meet the following specifications.

The rigidized booms shall be capable of reacting the following shuttle induced accelerations with a factor of safety of 4:

Rotational

Axis	Acceleration (rad/s^2)
X	0.0587
Y	0.053
Z	0.035

Translational

Axis	Acceleration (m/s^2)
X	0.052
Y	0.1891
Z	0.32

Boom lengths are as follows:

Booms	length
-y	17'4"
+y	13'1"
x	6'4"

The rigidized booms must have a first frequency greater than 1.2 Hz.

Sunshield Membranes

Candidate materials for the NGST sunshield are still under evaluation. Therefore ISIS will be unable to fly a sample of the NGST sunshield material. The sunshield material selected for ISIS was Kapton VN, 0.0005 inches thick. All interior surfaces are coated with 1000 Angstroms of Vapor Deposited Aluminum (VDA). The two outer surfaces are bare Kapton. VDA coatings are needed to lower the predicted temperatures between sunshield layers. The membranes are z-folded in such a fashion that the short booms will pull the membranes out first, then the long booms will pull out the remainder of the membrane material. Z-folding was selected to provide short vent paths should gas be trapped between the membrane layers during shuttle ascent to orbit. The membranes also have a ripstop system built into the layers at high stress areas to prohibit tear propagation, should membrane tearing occur.

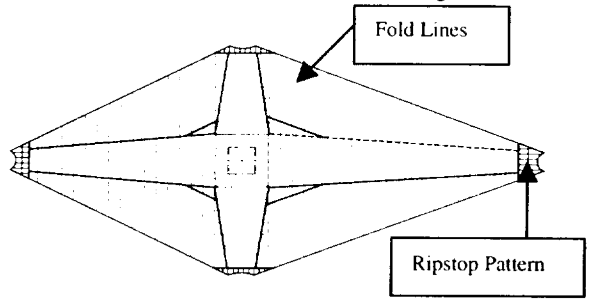

Figure 3: Membrane Layout

Figure 3 details the membrane layout with fold lines and ripstop locations.

Telescoping Mast

The ISIS mast provided by TRW Astro Aerospace, will be used to deploy the inflatable sunshield from within the Space Shuttle payload bay to a position twenty-two feet above the bay. This will provide protection from sunshield/Shuttle re-contact hazards. The current baseline design of the mast employs an

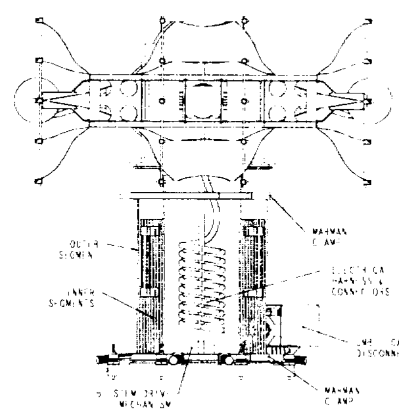

Figure 4: Mast cutaway view

electrically actuated telescoping mechanism. This mechanism consists of twelve concentric tubular sections and an electrically driven Storable Tubular Extendible Member (Bi-STEM) actuator. Each section is approximately two feet in length and will be deployed and locked into position sequentially. The bottom and outermost section is two feet in diameter and attached, using a Marman band to the Extra-Vehicular Activity Detachable Plate (Hitchhiker provided hardware). This outermost section is designed to support the loads generated by both the mast and the sunshield container during launch. Once deployed, the remaining sections are designed to support the sunshield and sunshield container under Primary Reaction Control System on-orbit limit loads. Both visual and electrical indicators will verify that the mast is completely deployed and locked into position. Figure 4 shows a cut away view of the mast.

Sunshield Container

The ISIS flight experiment is attached to the mast through a central canister. The canister is secured to the mast via a Marman clamp during launch and utilizes a bolted interface during operations. This central canister (Figure 5) provides mounting points for all the electronics and inflation system

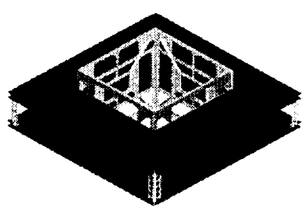

Figure 5: Sunshield Container

components and also acts as a thermal sink. In addition it provides the mounting point for the 4 booms and the support platform for the stowed membranes. Weight limitations and frequency requirements required numerous design iterations to achieve an acceptable design. Early analysis indicated that the booms and membranes would likely have most of their major dynamic modes between 0 and 5 Hertz. Because the booms are cantilevered off the walls of the central core and a stiff boundary condition was required, radial webs

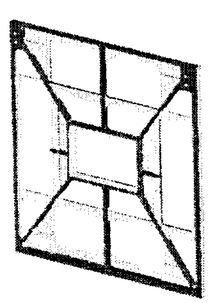

Figure 6: Container Wall

were implemented around the boom mounting location (see Figure 6). Material outside these webs was largely removed to accommodate weight restrictions. In an attempt to realize additional weight savings, the shelves were made from sheet metal (see Figure 7). While some weight savings could have been gained by manufacturing each side from a single large sheet of aluminum, ease of assembly drove the design of each side to be individual assemblies. The penalty of fastener mass was deemed insignificant relative to manufacturing and assembly ease.

Boom and Membrane Launch Restriant and Release System

The objective of the restraining system is to keep membranes and booms stowed during launch and then release them once on-orbit. Each boom has it's own restraint system. Each restraint system is made up of a boom restraint system (Figure 8), a membrane restraint system (Figure 9) and a single pin-puller actuator.

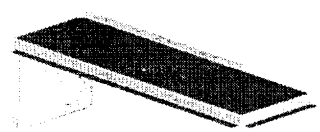

Figure 7: Shelf Assembly

The restraint system performs two functions, initially it functions as a restraint and then as a release and first motion system. As a restraint, the mechanism must carry the launch loads of the tip assembly mass as well as containing the membranes. Additionally, the mechanism must prevent inadvertent release of any component due to launch loads or entrapped air. As a release and first motion system, it must ensure controlled first motion and prevent boom re-contact with the central canister.

In order to use a single actuator, the release procedure accomplishes several actions. The actuator keeps the boom restraint mechanism locked in place

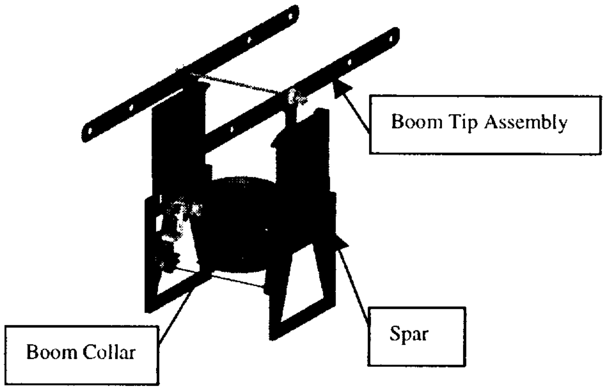

Figure 8: Boom Restraint System

against two spars. These spars are fastened to the upper and lower container shelves and the central canister. In turn, this causes the boom tip assembly, through a cup/cone arrangement, to engage the compression plate struts (Figure 9), holding the compression plates firmly against the shelves. When the pin puller is actuated, the boom restraint releases the boom assembly and is pushed forward by a spring. As the boom tip assembly moves out with the boom, the cup/cones are disengaged from the struts and the compression plates are free to rotate away from the membranes. The compression plate struts employ a torsional spring about their hinge with the central canister to ensure that they move in the correct direction and remain out of the way. In order to avoid inadvertent release, each cup/cone connection is independently preloaded. This assures that even under the most severe launch loads, there is a residual force that keeps the two sides connected. Moreover, the force between the compression plate and the shelves (independently adjustable) is set to prevent any relative motion between the membranes and the shelving in the worst launch load conditions.

The boom assemblies are restrained with a cup/cone arrangement on either side of the boom spool. In the stowed configuration the tip assembly engages the spars through the cup/cone interface. All launch loads then go through the spars. In order to restrain the boom assembly, a hook system is utilized. There is one hook system per spar, fixed to the spars. The hook engages a pin on the ladder structure at the boom collar pivoting point. The pre-load on the pin is achieved through an adjustable spring. Each hook system is independently adjustable allowing each cup/cone arrangement to be evenly pre-loaded. Control of boom tip motion is achieved by a groove in each spar. The pin in the boom collar slides along the groove. The groove profile prevents interference between the tip assembly and the main structure. During the first two inches of the deployment, the pins remain in the groove. Once the pins start sliding, the struts holding the compression plates disengage. This allows the compression plates to release.

After the release of the compression plate, the membranes are unrestrained and could deploy in an uncontrolled manner. In order to avoid this, a membrane restraint clip holds the membranes to

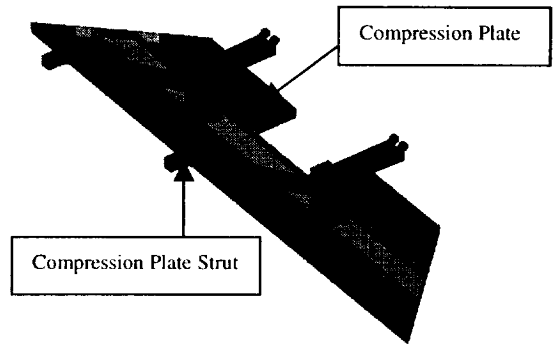

Figure 9: Membrane Restraint System

the shelves and only allows them to deploy one layer at a time. The clips are made of spring steel to provide a force against the membranes and squares of Delrin coated fiberglass cloth. These Delrin squares provide separation between the z-folds of the membranes and are loaded against the shelf with the spring steel. The whole assembly is attached to the canister side.

Boom Inflation System

The boom inflation system is a nitrogen gas system with flight heritage from the Spartan carrier cold gas systems. The system contains a 68 in^3 nitrogen tank at 3000 psi. The gas is regulated down to the delivery pressure of 3.2-3.7 psi. A closed loop, software commanded fill sequence controls the flow of gas into the booms. Each boom can be independently filled and vented.

Data Acquisition Sensors

The current baseline instrumentation suite for the post-deployment, dynamic characterization phase of the flight test consists of accelerometers and force gages. These will determine frequency response characteristics and damping. Video cameras will also be used to visually document the dynamic testing. Tri-axis accelerometers will be located at the tip of each boom, on the sunshield container base plate, and at the root of the mast. Force gages (single-axis) will be located at the four interface points between the sunshield container and the mast. The frequency range of interest has been defined such that the four major modes of the system can be recovered from 0.1 to 5Hz. An analog low pass filter will eliminate frequencies over 5Hz in the data sets recovered. The data acquisition and signal conditioning system is located in the sunshield container and has a sampling rate of 50 Hz such that at least 10 samples will be gathered during the shortest vibrational period. Table 1 presents a list of the accelerometer and force gage locations and specifications, while Fig. 10 provides a schematic of the instrumentation locations.

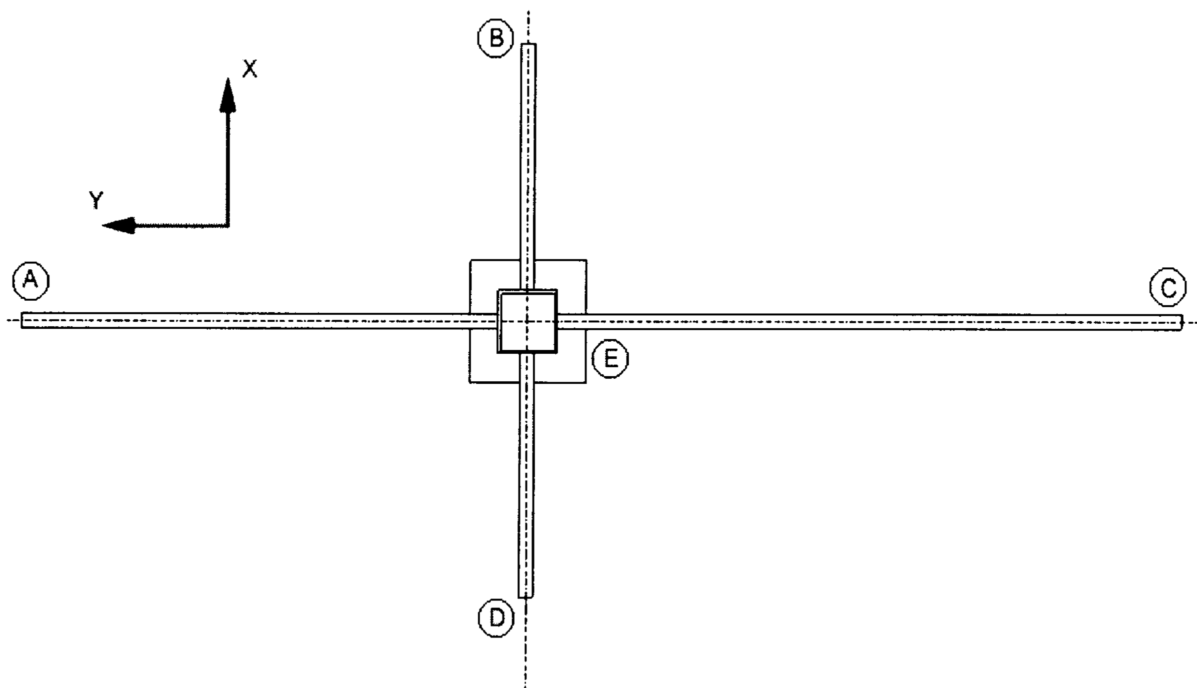

Fig. 10: Instrumentation locations for ISIS flight experiment.

Location	Sensor	**Frequency range**	**Max. Level [1]**	**Qty**	**Channels**
A (Medium boom)	Tri-axis accelerometer	5 Hz Max	0.1g	1	3
B (+X Short boom)	Tri-axis accelerometer	5 Hz Max	0.1g	1	3
C (Long boom)	Tri-axis accelerometer	5 Hz Max	0.1g	1	3
D (-X Short boom)	Tri-axis accelerometer	5 Hz Max	0.1g	1	3
E (Sunshield container base plate)	Tri-axis accelerometer Single-axis force gage	5 Hz Max 5 Hz Max	0.1g 55 N	2 4	6 4
F (Root of mast)	Tri-axis accelerometer	5 Hz Max	1g	1	3
					25 (total)

Notes:
[1]: The maximum measurement level requirements for the sensors were calculated based assuming a one-third level Shuttle PRCS excitation.

Table 1: Baseline instrumentation for post-deployment dynamic characterization of the ISIS flight experiment

ELECTRICAL DESIGN

The Command and Data Handling (C&DH) system functions as the single interface between ISIS and instrument subsystems and Hitchhiker. The C&DH subsystem consists of the following components: (1) a Housekeeping RSN Card (ESN included), (2) a Relay Card and (3) a PCM Encoder System (Aydin Telemetry, Model MPC-800). The PCM Encoder System is a data acquisition system component that will provide all of the signal conditioning and encoding functions. The MPC-800 is designed to combine all of the most commonly required functions in a very small modular package. The unit is constructed from stackable conditioning and overhead modules that contain discrete, thick-film hybrid, and custom ASIC circuit technologies. The PCM Encoder System will sequentially sample the instrumentation analog signal, quantize the pulses and converts each pulse into a binary word, resulting in a bit sequence. This will be done at a rate no higher than 50Hz. The Housekeeping RSN Card (MIDEX-MAP heritage) will accept a PCM output data stream from the MPC-800 and will provide commands to the Relay Card. Power to the Boom Heaters will be generated by the High Voltage Power Converter (HVPC) and switched by the Relay Card 59V Bus, via commands from the H/K RSN Card. Power will be provided to the Inflation System and the Sunshield Boom Restraints via the Relay Card 28V Bus. The ESN custom ASIC includes a UTMC UT69R000 16-bit Processor, two 8254 Counter/Timers, a 8255 Programmable Peripheral Interface, a Serial Telemetry and Command Interface, a 96 Kword RAM, and a 12-bit A/D Converter (up to 23 analog channels). A block diagram of the C&DH subsystem is shown in Figure 11.

FLIGHT TESTING

Dynamic testing will take place once the sunshield has successfully deployed and the inflatable booms have been rigidized. In order to characterize the dynamic behavior of the system, inertial loads representative of scaled NGST flight loads will be applied to the sunshield by executing a series of Space Shuttle maneuvers. Two different acceleration loads have been defined for the NGST observatory: (1) a translational acceleration normal to the sunshield plane and (2) a rotational acceleration about the axis described by the two short booms. Plans call for using one-third level thruster firings of the Shuttle primary reaction control system (PRCS) to excite the sunshield by imparting impulsive accelerations on the structure. The impulse profile for these thruster firings is approximately a square pulse with a minimum duration of 80 ms and a peak acceleration level of 0.327 m/s^2 (equivalent to one-third of full PRCS loads). An analysis was performed to validate the use of the baseline shuttle maneuvers to excite the sunshield.[1] The analysis demonstrated that shuttle thruster firings that impart a translational acceleration in the direction normal to the plane of the membranes provide sufficient excitation to recover data to characterize the dynamics of the structure. The rotational maneuver has been eliminated from the on-orbit operations because of dynamic coupling with the deployable mast, which has a first bending mode in the frequency range of interest of the sunshield. The ISIS mission will require the use of the Shuttle payload bay cameras for additional measurements. These measurements include visual indication of membrane separation, membrane mode shapes and verification of deployed envelope.

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1. Sebastien Lienard, John D. Johnston - Analysis and Ground Testing for Validation of the Inflatable Sunshield In Space Experiment – April 2000, AIAA-2000-1638

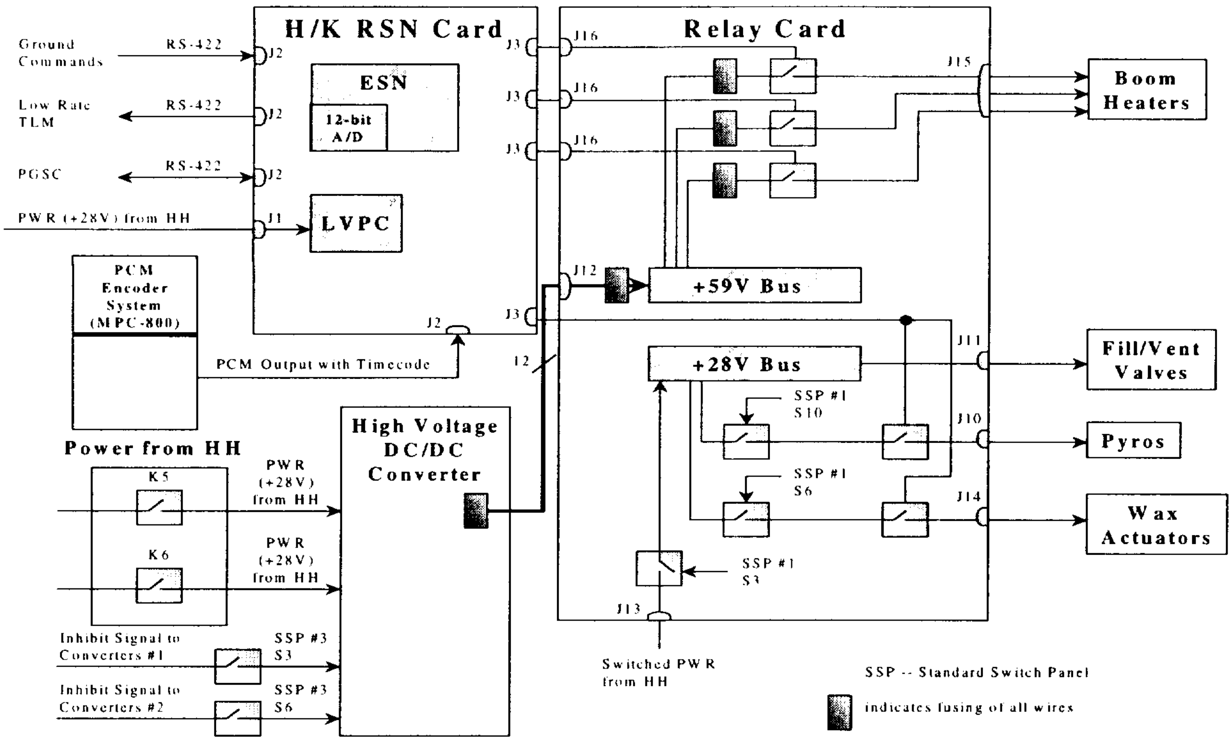

Figure 11: C&DH Block Diagram