Development of a Remote Sensing and Microgravity Student GAS Payload

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Abstract:

The G-781 Terrestrial and Atmospheric Multi-Spectral Explorer payload (TAMSE) is the result of an educational partnership between Broward and Brevard Community Colleges with the Association of Small Payload Researchers (ASPR) and the Florida Space Institute, University of Central Florida. The effort focuses on flying nine experiments, including three earth viewing remote sensing experiments, three microgravity experiments involving crystal growth, and three radiation measurement experiments. The G-781 science team, composed of both student and faculty members, has been working on this payload since 1995. The dream of flying the first Florida educational GAS experiment led to the flight of a passive Radiation dosimetry experiment on STS-91 (ASPR-GraDEx-I), which will be reflown as part of TAMSE. This project has lead to the development of a mature space science program within the schools. Many students have been positively touched by direct involvement with NASA and the GAS program as well as with other flight programs e.g. the KC-135 flight program. Several students have changed majors, and selected physics, engineering, and other science career paths as a result of the experience.

The importance of interdisciplinary training is fundamental to this payload and to the teaching of the natural sciences. These innovative student oriented projects will payoff not only in new science data, but also in accomplishing training for the next generation of environmental and space scientists. The details the TAMSE payload design are presented in this paper.

Introduction

Broward Community College and Brevard Community College and the Association of Small Payload Researchers (ASPR) will fly a series of student experiments through NASA's GAS payload program. Three earth viewing remote sensing experiments, three microgravity experiments involving crystal growth, two radiation measurement experiments, and 1 genotoxicology experiment will be flown in a standard, 5 cubic foot GAS canister.

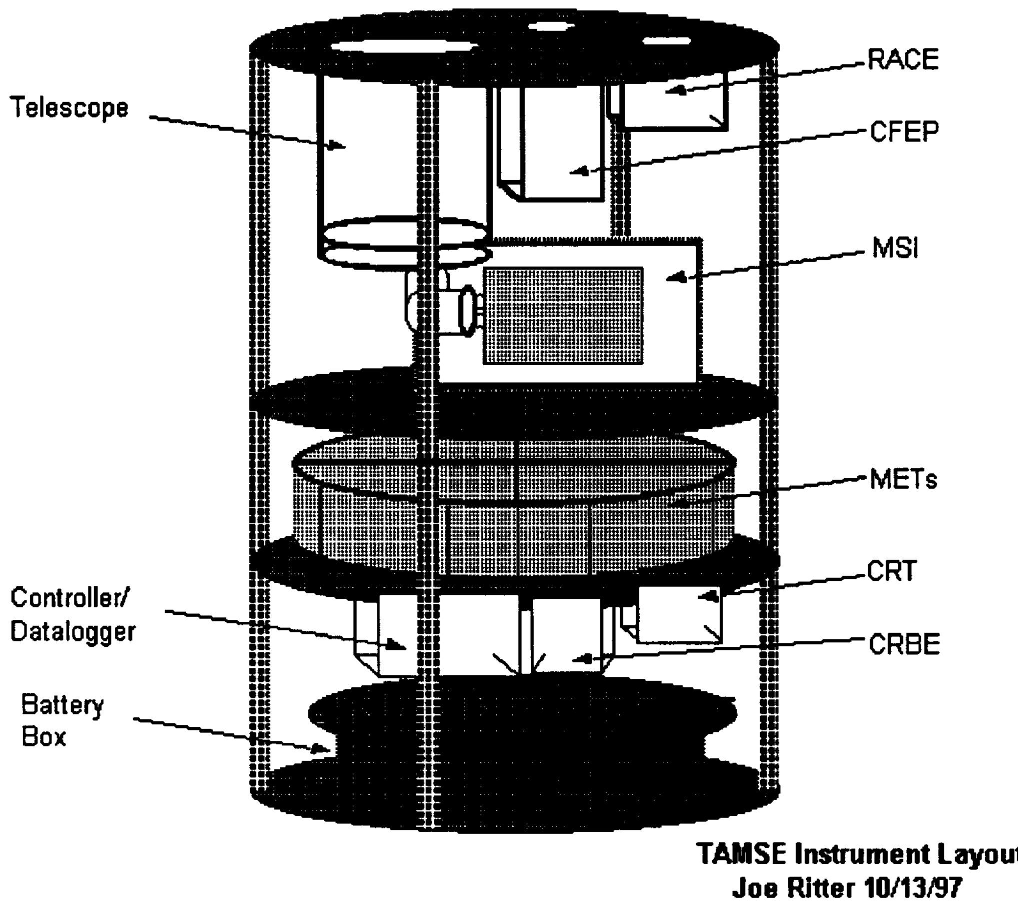

Figure 1. The TAMSE GAS payload

The TAMSE (Terrestrial and Atmospheric Multi-Spectral Explorer) payload has three main levels. The first (top) level houses the optical remote sensing experiments. The second (middle) level houses three microgravity crystal growth experiments, and a biological genotoxicology experiment. The third (bottom) level contains a sealed battery box, the payload control electronics, and two cosmic ray measurement experiments. A brief overview of the scientific objectives and design for each of these nine experiments presented here.

Experiment Descriptions

The primary remote sensing experiments consist of 3 modules: A simple yet rugged Sagnac interferometer acting as a Fourier Transform Spectrometer (MSI), a separate multiple channel discrete cell radiometer (RACE) and a CCD camera with 3 wide band color filters (CFEP). The top of atmosphere upwelling spectral radiance distribution will be measured from 300 to 1000 nanometers. Together these instruments will provide an integrated dataset having both high spectral and spatial resolution as well as good absolute radiometric accuracy. Data products will include: vegetation indices, phytoplankton concentrations, and atmospheric aerosol characterization.

Multi-Spectral Imaging Experiment (MSI)

The top of atmosphere upwelling spectral radiance at nadir from 300 to 1000 nanometers will be measured using the MSI. Light from the Earth and atmosphere will be focused in a 1 meter focal length telescope and processed through a Sagnac interferometer. The resulting hologram will be recorded on 35mm film using a Nikon F3 camera housing with a 250 exposure MD-4 motorized film back. This configuration constitutes a holographic Fourier transform spectrometer. A MOSFET will be used to trigger the camera shutter. The controller will determine if enough light is present and will control the interval between photographs. When the film is retrieved and developed the interference pattern will be Fourier analyzed yielding the spectral distribution. Then a 2-D inverse Fourier transform will be applied yielding a partial image. The reduced dataset will yield the equivalent of an image at many different wavelengths simultaneously. The image files produced by this device will be 10 (x-axis width) x 242 (y-axis height) x 375 (spectral-axis depth) pixels each having 12 bit resolution. This data set will then be corrected for absolute radiometric accuracy. The images will finally be joined end to end along the x-axis to form larger image mosaic. This instrument is being constructed as a joint effort between the Association of Small Payload Researchers (ASPR), and Broward Community College.

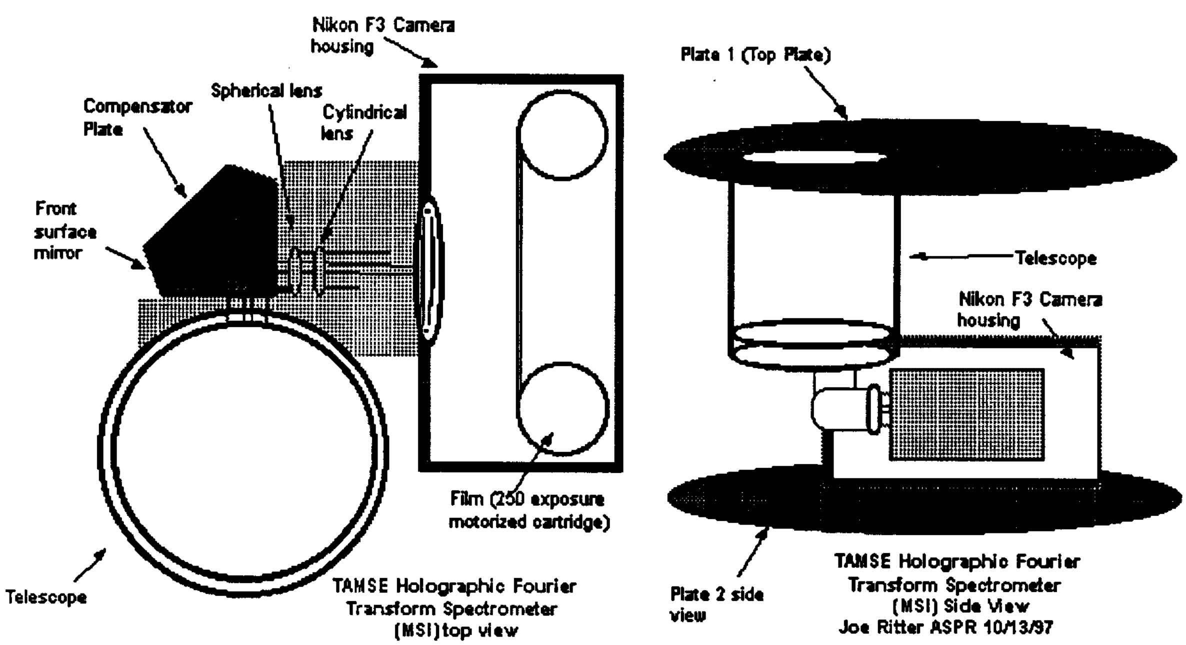

Figure 2. The Multi-Spectral Imaging (MSI) Holographic Fourier Transform Spectrometer

Radiometry and Calibration Experiment (RACE)

The top of atmosphere upwelling spectral radiance at nadir over a 1 degree field of view at 4 fixed spectral bands will be measured. RACE and the MSI will view the same area of the earth's surface simultaneously but utilize completely separate optical and electronic systems. Although the spectral resolution of the MSI is quite high, absolute radiometric calibration of the MSI on orbit is challenging. Using RACE, radiometry at 3 10 nm wide spectral bands (440, 670, and 860 nm) will be performed using integrated photodiode amplifier packages. Spectral selection will be accomplished through the use of narrow band interference filters. Dynamic range optimization will be accomplished through the combined use of absorbing neutral density filters and by altering photodiode amplifier gain. Multiple temperature measurement sensors will be used to establish ambient instrument conditions for use in post calibration and post mission data reduction. Data from temperature and radiometry channels will be digitized and recorded with 12-bit resolution using a custom designed microcontroller. The overall dimensions of the RACE module (figure3) are 3.5îx3îx3.3î and it weighs only 250 grams

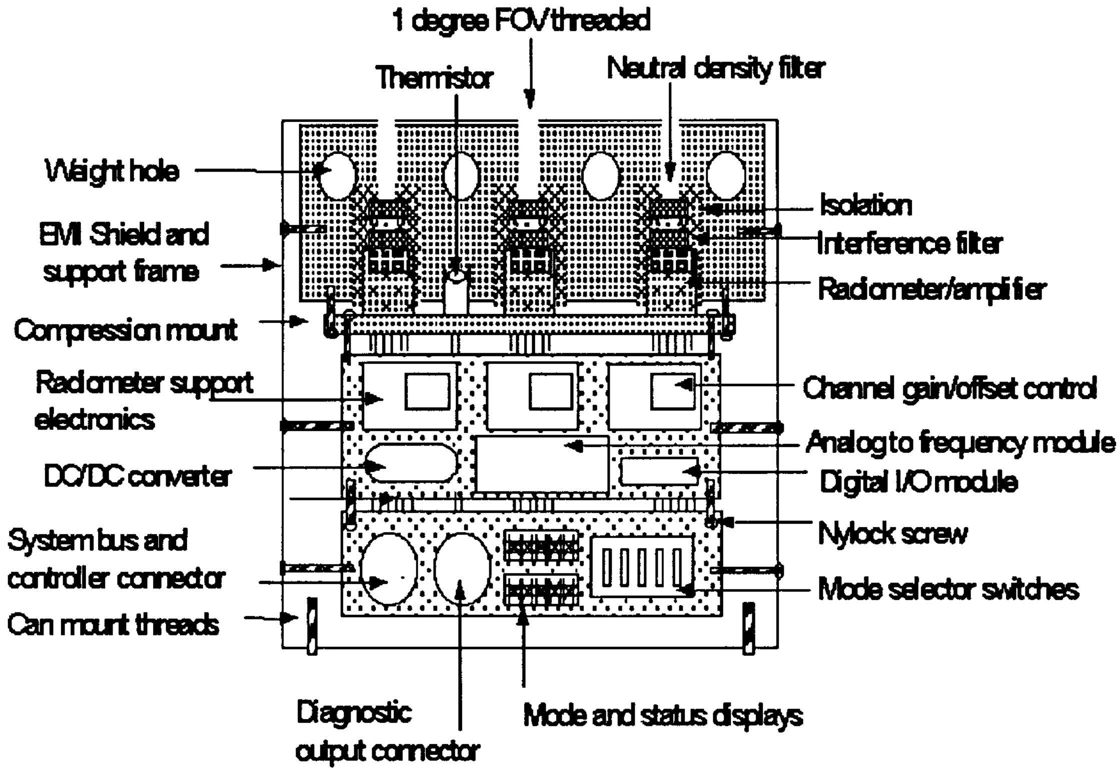

Figure 3. The Radiometry and Calibration Experiment (RACE) Module Joe Ritter 1997

The Radiometer will provide spectral data for two uses. The primary objective is to provide accurate cross calibration with the holographic Fourier transform spectrometer (MSI). The RACE module will provide sufficient instrument ambient condition data so as to allow reasonable accuracy in retrieving individual spectral channel data. The RACE module will provide absolute radiometric data from individual spectral channels. This dataset will be used to effect an absolute radiometric calibration of the MSI spectrometer. The cross calibration of the MSI instrument will provide an integrated dataset having both high spectral resolution and reasonable absolute radiometric accuracy. The secondary and independent science objective for RACE will be to provide data for computation of various vegetation indices as well as to remotely determine ocean phytoplankton concentrations. This instrument is being constructed in cooperation with the Association of Small Payload Researchers (ASPR.

Color Filter Earth Photography Experiment (CFEP)

This experiment will use a standard CCD based video tape recorder with a wide-angle lens. The video camera used will be a Sony CCD-TR101/TR805 which has been specially modified to accept external triggering and power activation. The auto-focus function has been disabled, the focus set to infinity and the infrared blocking filter has been removed to allow near IR measurement. The camera will be housed inside an insulated custom-machined aluminum container (4îx4.75îx5.5î) which will be mounted on the underside of plate 1. The container will minimize any EMI output from the experiment. The camera spectral response over 3 wide bands will be determined for different CCD gain settings. The 3 camera channel gain settings will be recorded on one audio channel in order to separate individual images into absolutely radiometrically calibrated wideband RGB images.

Cosmic Ray Trace Experiment (CRT)

The CRT experiment will record the path and intensity of cosmic rays as they pass through various photographic emulsions. The reaction of the cosmic ray with various metals will also be explored. Up to ten layers of photographic film will be placed in a holder, and 5 such holders will be used. All will be contained within different a thickness of lead shielding. When retrieved and developed the traces will be digitized and the radiation path and reactions with the various metals will be analyzed. Dosimetry for 5 different particle energy bands will be attempted.

Cosmic Ray Background Radiation Experiment (CRBR)

The cosmic ray background intensity will be monitored using a standard Geiger tube. The number of counts per energy interval (energy spectrum) will be recorded using a counting circuit interfaced to a micro controller/datalogger. This dataset will be integrated with the data from the CRT experiment.

Modular experiment trays (MET 1-4)

Four modular experiment trays (METs) will be mounted to the top of plate 3, and will house 3 crystal growth chambers and 1 genotoxicology experiment.

Crystal Growth Experiment-1 (MET1-CGE-1)
Calcium Tartrate crystals will be grown using a gel and diffusion method. The gel growing medium will be made with sodium silicate and tartaric acid. The gel will be mixed and set in the module before the flight integration. Two valves will control the start and end of the diffusion process. This experiment is intended as a follow up of Dr. Lind's experiment aboard the Apollo-Soyuz mission. The experimental apparatus will be very similar.

Crystal Growth Experiment-2 (MET2-CGE-2)
Inside the module there will be two sealed containers. One container will carry Dimethylamine with a small sub-compartment that will mix baking soda and citric acid. The mixing of citric acid and baking soda will produce carbon dioxide that will combine with the dimethylamine to form crystals. The second container will hold three sub-compartments. Two sub-compartments will carry the two compounds to be mixed. A third sub-compartment is reserved for mixing and crystallization of the two compounds.

Crystal Growth Experiment-3 (MET3-CGE-3)
CuInSe2 thin films will be electro-deposited from aqueous solution. Metal salts of Cu(SO4)3, In(SO4)3-Hydrate, and SeO2 will be dissolved in a 1:1 mixture of deionized water and ethylene glycol (50ml of each for a total bath volume of 100ml). The fluid will be contained in a precision-machined fluid cell made from high molecular weight polyethylene, which has minimal structural degradation for temperatures down to -40°C. Three (3) electrodes will be used. A molybdenum working electrode will act as the sample substrate. A platinum wire will be used for the counter electrode and a saturated calomel electrode will be used as a reference electrode. The deposition process will be active for only 10 minutes once orbit is obtained. A potentiostat control system will regulate the electro-deposition rate. Epoxy will be used to seal the entire cell, which will be further enclosed in a leak proof plastic container.

Genotoxicology and Plant Seed Experiment (MET4-GPSE)

Texas A & M University and ASPR have constructed a genotoxicology experiment to determine the degree to which DNA, both in vivo (seeds) and in vitro, is damaged by exposure to cosmic radiation in a space environment. DNA will be extracted from tissues of a variety of vertebrate organisms including man, chicken, and fish. The DNA samples will be in a buffer solution containing DMSO (to lower the freezing temperature thus preventing ice crystal formation), Tris, and EDTA (to provide stabilization of the naked DNA). The samples are loaded into sterile quartz cuvettes and sealed. Identical control samples will be prepared, but will not be flown in space. Of the samples flown in space, some will receive shielding with lead foil, and others will be unshielded. The DNA will be assayed by means of the strand-break analysis to measures the average length of the DNA in each sample. This will allow us to estimate the effectiveness of partial shielding and to help determine dose-response relationship (increase in strand breaks with increase in exposure). Radiation can cause nucleotide substitutions. The process involves the initial production of single or double strand breaks, either as a result of the direct interaction of the DNA with the particle, or by interaction with radicals. In vivo the strand break is either repaired correctly, resulting in no mutation, or misrepaired, resulting in a nucleotide substitution (mutation). Because the naked DNA in the vials is in a cell free environment, there is no opportunity for repair to take place. Only strand breaks will be measured with this experimental design; however, there is a direct correlation between the number of strand breaks and mutation rate. In order to detect another type of mutation, seeds of the mustard plant Arabodopsis will be flown, then grown on earth to look for the effects of chromosome damage in somatic cells by means of flow cytometry. Germination and viability will also be compared to a control population. In addition to being flown on TAMSE, a version of this experiment (ASPR-GraDEx-I) constructed by ASPR, Texas A&M, and Belen Jesuit High School (Miami Fl.) flew on STS-91 in May of 1998.

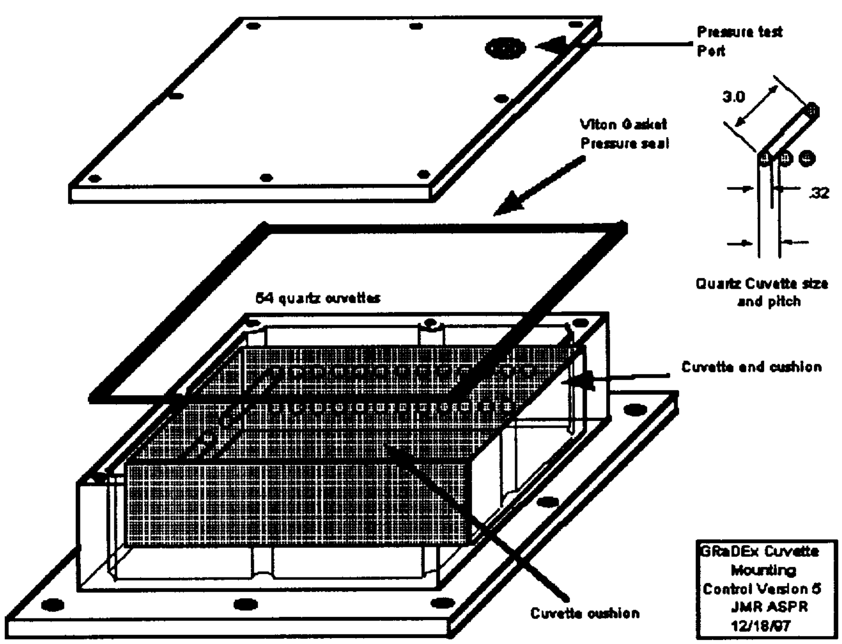

Figure 4. Genotoxicology and Radiation Dosimetry Experiment (ASPR-GraDEx-I)

Operational Scenario

Approx. 8-10 hours after launch, the shuttle will be inverted allowing an earth viewing attitude from the shuttle cargo bay. The payload door will open and power to all experiments (except the MSI and CFEP) will be initiated.. The CRBR, MET-CGE-1, MET-CGE-2, and MET-CGE-3 (crystal growth experiments) and RACE will begin immediate operation. Ten minutes after that MET-CGE-3 will shut down. During a period of viewing the day side if Earth, the MSI and CFP experiments will be activated. A small photo-sensor will determine if the ambient light is sufficient and when it is, they will make their first measurements. As late as possible in the flight, after a period of continuous Earth viewing, the MSI and CFP will be turned off and the valves to the MET-CGE-1, and MET-CGE-2 crystal growth experiments will be shut off. Immediately afterwards the CRBR experiment will also shut down.

Payload Support Structure

The TAMSE support structure of consists of 4 main round aluminum plates separated by structural columns. The columns separate the payload into 3 main levels. The structure is a system of shelves upon which experiment modules are bolted. The plates are made of 6061 T6 aluminum 3/8" thick. The modular experiment trays are constructed of 1/16" thick aluminum sheets.

Level 1 houses the earth viewing experiments at the top of the canister. These three experiments, the MSI telescope, CFEP, and RACE are mounted to the underside of the top plate (plate 1). The top plate has a 3.5 inch diameter circular opening for the telescope a 1.5 inch diameter circular opening for the video camera (CFEP experiment). It also has three small 1 cm diameter holes (apertures) for the RACE module.

The top of plate one is bolted to a mounting ring (or bulkhead) just beneath the GSFC 16 inch diameter window. The window at the top of the canister is covered by the door of the motorized door assembly until a viewing attitude is achieved. The top plate (plate 1) serves several safety functions. It provides a shield capable of containing parts moving inside the container from any failed mechanical substructure. It also serves as an aid in EMI shielding by providing a conductive closing lid to the experiments. With its presence the canister acts as a faraday cage. The second (middle level) contains the modular experiment trays (METs) shown in figure 1.2.6A. The METs are constructed of 1/16th inch thick aluminum. The third (bottom) level (between plate 3 and plate 4) houses the battery box along with the control electronics. In order to prevent movement of the internal TAMSE structure (instrument package) relative to the to the GAS canister, bumpers (figure 2.1.2) are attached to the bottom of plate 4.

The battery system consists of 60 Hawker (formerly Gates) D cells. They are arranged in 4 parallel banks of 15 cells each and contained within a hermetically sealed battery box. The box is vented to space. The free volume is minimized. The system will be proof pressure tested to 22.5 psi. The battery box cylindrical housing has an inner diameter of 12 inches and is constructed of a single 4 inch thick plate of 6061-T6 aluminum that has been bored out with a mill and then finished on a lathe to leave a surrounding flange to accommodate a Viton®[Viton® is a registered trademark of DuPont Dow Elastomers] O ring at the top of the flange where bolt holes that match the top lid form a pressure seal. The closed bottom of the cylinder has 6 bolt holes that secure the battery box to the bottom plate of the overall structure. The battery box lid is made from a separate 3/8 inch thick 6061-T6 aluminum plate. The lid contains the battery systems purge ports as well as feedthroughs to deliver electrical power.

Payload Control

The payload controller electronics all reside on a single PC board that contains two redundant Motorola MC68HC11A8-16 HCMOS single chip micro-controllers along with battery backed up CMOS SRAM memory. The onboard controller will control the activation times of the experiments as well as data acquisition and data logging. The board will also hold power regulation as well as additional digitizing and control electronics. The controller will be housed in a grounded aluminum EMI shield.

Safety assessment

Possible hazards, which cannot be eliminated, have been reduced to the lowest possible level through the use of a variety of safety devices. This will be demonstrated by test, by modeling and by similarity with systems used in previous flights. Flame hazards are kept to a minimum by filling the GAS container with dry nitrogen before launch and mechanical strength is assured through over design and extensive mechanical testing.

The concerns associated with the electrical system are the possibility of evolving H_2 /O_2 or electrolyte leakage due to short circuit, overheating, reverse current, overdischarge, container overpressure, release of battery gases accompanied by an ignition source, or a combination of these conditions. The hazard due to escaping of aqueous electrolyte from the cells resulting in corrosion of the container, its contents and ultimately the GAS canister have been assessed. The precautions are as follows: The batteries are encased in a sealed aluminum box and held securely by internal support structures. The inside of the battery box will be coated with a nonconductive material, Conathane EN-11, which is chemically inert to the battery electrolyte. Potential gas is vented overboard using two standard NASA 5 psi differential pressure relief valves. Prior to launch, the GAS canister and the battery box will be purged with dry nitrogen gas by NASA Ground Operations Personnel in order to reduce the residual oxygen/hydrogen content. Short-circuiting is controlled by fusing the negative leg of each cell string as close to the cells as possible within the canister. Parallel cell strings are diode isolated to protect against reversal. Fuses are sized to protect the batteries from an over current condition. Structural analysis indicating appropriate loads with an ultimate safety factor and a fundamental frequency have been performed. This analysis will be reviewed by NASA GSFC. All materials have been approved for flight by the GSFC Materials Branch/Code 313.

Conclusion

The design and fabrication of the TAMSE payload represents several years of time and learning invested by students and their mentors. The TAMSE investigators and authors of this paper believe that interdisciplinary technical training of our youth is critical to the long-term interests of the United States. Only by maintaining a competitive technical edge will the United States continue to be a world economic leader. We are both grateful and proud to live in a country where opportunities such as NASA's GAS program are made available to educators and to students. In the same spirit, data from the TAMSE and ASPR-GraDEx-I payload will be made available to educators who contact the authors.

Acknowledgments

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