CAPABILITIES AND CONSTRAINTS OF TYPICAL SPACE FLIGHT HARDWARE

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Introduction

The Space Experiments Division is in the business of performing ground based low gravity testing and designing experiment hardware for space flight on the Space Shuttle and in the future, Space Station Freedom. As witnessed in combustion work, the reduction of gravity brings forward previously negligible processes and parameters. In a similar manner, the design of experiments for microgravity operation aboard the Space Shuttle must consider parameters that are often not factors for laboratory hardware.

Accommodations

One of the first requirements that needs to be defined is the size selection for Shuttle accommodations. This selection is mostly driven by experiment requirements and manifest availability. The accommodations aboard Shuttle fall into two categories, that is habitable areas and the cargo bay. Obviously, the habitable areas permit crew interaction (hands on options) with the experiment. Cargo bay experiments are required to be more automated. Also, the safety requirements associated with crew presence are not a concern in the cargo bay.

The Space Shuttle provides several accommodations within the habitable area. Options consist of the Middeck area and the Spacelab (Spacehab is future option). Each area has its limitations and advantages. A summary of the resources available in each area is provided in Table 1.

Middeck

The Middeck area is the crews' living space. The prime experiment accommodation is in the place of middeck stowage lockers. The lockers are used mainly for Shuttle and crew stowage items but based upon the mission, several of the locker spaces are available for experiment hardware. The hardware can be designed to fit into a stowage container which provides 0.56 m^3 of volume and 24 kg weight carrying capacity.

Additional volume and weight is accommodated by interfacing in place of the stowage container(s). Experiment hardware can occupy the space of two middeck stowage lockers structurally and several lockers if not structurally connected. The more space that is allocated for a single experiment, however reduces the opportunities for flight. The services provided to an experiment in the middeck locker area are basic (namely; space, low power and crew interaction). The middeck locker area does provide ample flight opportunities since it is an integral section of the Shuttle. Experiments slated for Middeck opportunities are considered as secondary payloads which are evaluated for each Shuttle flight.

The Middeck area can also provide accommodations in a Middeck Accommodations Rack (MAR). This rack is mounted along port side in the Middeck. It provides additional services such as cooling, increased volume (0.42 m^3) and increased weight. The MAR has not been yet integrated into a Shuttle for flight.

Spacelab

The Spacelab module provides a complete laboratory setting for conducting experiments. The module consists of twelve equipment racks and additional mounting locations along the floor for experiment hardware. A summary of the rack features are listed in Table 1.

The Spacelab racks provide a variety of resources to the experimenter. The Spacelab rack services closely resemble the services associated with normal laboratories. Along with the larger volume and weight capacity available compared to the Middeck accommodations, the rack has provisions for thermal control (avionics air loop or liquid cooling loop), and command and data management.

Another provision for experiment operation within the Spacelab is a glovebox facility. The glovebox is a sealed work area for the performance of small experiments. The glovebox experiments are manifested as stowage items and operated in the confines of the glovebox. The facility provides a level of containment that permits operations using small quantities of toxic, irritant or potentially harmful materials.

A small version of the Spacelab is the Spacehab. The Spacehab is being developed to provide either 61 lockers (Middeck type) or 41 lockers with 2 racks. A Spacehab rack provides 1.2 m^3 of volume (two areas of 2.03m x .48m x .56 m) and is able to support 567 kg of payload. Other services provided by the Spacehab rack is similar to those provided by the Spacelab rack. The Spacehab is a new Shuttle accommodation that is yet to be flown.

Crew operation and observations of experiments is available to all accommodations within the habitable areas of the Shuttle. The rack accommodations generally offer the most resources/services to the experimenter but the lockers have the greatest flight opportunities.

The other accommodation area for microgravity experiments (secondary payloads) is in the Shuttle cargo bay. Two of the accommodations are the Getaway Special (GAS) Canister and as a payload on the Mission Peculiar Experiment Support Structure (MPESS).

GAS CAN

The GAS can is a cylindrical pressure vessel that can house up to a 90 kg experiment payload. The GAS can provides the simple services of 0.14 m^3 sealed volume and activation control. The GAS can being basic simplifies the integration and design work for the experimenter. The GAS cans are generally manifested as ballast on the Shuttle so flight opportunities are determined relatively late in the processing flow, but are often.

MPESS

Two MPESS's have been connected to form the United States Microgravity Payload (USMP). A description of the payload accommodations on USMP are described in Table 1. The USMP accommodation has resources similar to the Spacelab. It only lacks the crew interaction.

The cargo bay accommodations lack the crew interaction provided within the habitable areas of the Shuttle. The loss of this feature requires the experiments to be more automated. For USMP payloads, interactive control is available through the command and data management system (CDMS).

The accommodations described are the common ones aboard the Shuttle. For all these accommodations, the experimenter time-line is limited to the length of the Shuttle mission which is generally about five to ten days (extended duration of 13 days has been achieved) and sharing of resources among experimenters. The time-line will be expanded with the future use of Space Station Freedom (SSF). Rack accommodations are being developed for SSF.

HARDWARE DESIGN

The experiment hardware design gets its origins from the laboratory rigs developed in performing 1-g tests. The process to get to a flight experiment would seem to be one of packaging. Requirements based on Shuttle safety and environment, however does not allow us to just package components. Parameters are added or more importance is placed on parameters as the hardware is transitioned to the Shuttle.

MATERIAL SELECTION

Today, health concerns from materials are addressed in their uses in the laboratories. Material Safety Data Sheets (MSDS) provide guidelines for safe use of materials and protective equipment necessary when handling certain materials. The measures taken on the ground, however, are not always available on the Shuttle, therefore extra precautions must be taken. All materials used on the space flight hardware must be evaluated for its acceptability.

Metallic materials are evaluated for their resistance to corrosion and contamination, resistance to stress corrosion cracking, compatibility with oxygen and fluid systems, strength, and fatigue endurance. Along with the metallic material selected, attention must be paid to the coatings applied to the metals.

Non-metallic materials generally come under the majority of the scrutiny. The major concerns for non-metallics are flammability and toxicity. Both of these are of less concern for experiments located in the cargo bay (depending on experiment provided environment). Common plastics, tapes and adhesives used in the lab are usually not acceptable for space flight use.

ENVIRONMENTAL CONSTRAINTS

The hardware components must be evaluated for their ability to operate and survive the environment imposed by a Shuttle flight (launch, orbit and landing). An area of concern for components is the ability to survive the launch random vibration loads. The vibration loads are dependent upon the accommodation but generally range up to 12 g's [rms] (at the interface with the experiment; might be larger at component due to amplification). In order to deal with the vibration environment, some components require vibration isolation, modifications for vibration resistance, or substitution.

The thermal environment of the Shuttle is also a concern for the experiments in the cargo bay. The cargo bay temperatures exceed the operating limitations of most commercial electronics and the temperatures affect experiment gases and liquids (phase change, pressure changes). Due to the elimination of buoyancy driven convection flows in the microgravity environment, even the shirt sleeve environment of the manned areas causes thermal problems. With the lack of convection, some experiments design in forced convective flows to keep hardware within operating limits and below Shuttle temperature limits (touch temperature limit of 45 °C). The thermal concerns also direct component selection to be based upon power consumption.

An obvious aspect of space flight that is sometimes overlooked in evaluating component acceptability is gravity dependency. Some mechanisms rely on gravity for proper or safe operation. An example of this is the ejection of a storage disk. The mechanism consisted of a spring load to overcome frictional drag due to the weight of the storage disk. Without the gravity force, the spring load propelled the storage disk into the Shuttle cabin area.

These factors and others make the transition to space flight hardware more than a packaging task. They also work to add constraints to the hardware.

OPERATIONS

Even though some of the Shuttle accommodations resemble laboratories in terms of services provided, they do not in terms of operations. All experiment operations and crew interactions with hardware are controlled by the Shuttle safety requirements. Safety has to be at the center of hardware design and hardware operations. Experiment hardware or operation shall not damage or impair the Shuttle nor harm the crew.

This requirement has far reaching implications in the hardware design and operation. Simple operations performed on the ground such as sample change out are complicated in space. The procedures for the sample change out must consider items such as sharp edges, surface temperatures, release of hazardous materials (combustion gases) or electrical shock. The experiment procedure during a space flight must have controls to prevent any of the possible unsafe conditions before it would be approved for performance. Operation of the experiment requires extra steps and extra hardware features to aid the crew in the weightless environment.

The automated operation of experiments are still subjected to the requirement of safe operations. For those type of experiments, electrical and software protection are required.

CONCLUSION

The accommodations for experiments provide space up to 1.75 m^3 and structural capacity of 300 kg. The services usually available in ground based laboratories such as power, cooling, data management can be found within the Shuttle accommodations. The experimenter receives the services necessary to conduct their experiment. Space flight safety and environmental requirements constrain the design of the experiments. Factors such as material acceptability, vibration survival and non hazardous operations at times eliminate experiment components or operational flexibility.

TABLE 1 SUMMARY OF SPACE SHUTTLE / SPACE STATION ACCOMODATION RESOURCES

RESOURCE	MIDDECK LOCKER SINGLE	MIDDECK LOCKER DOUBLE	SPACELAB RACK SINGLE	SPACELAB RACK DOUBLE	GLOVEBOX
VOLUME	0.066 m^3 .46x.27x.52m	0.13 m^3 .46x.55x.52m	0.42 m^3 .44x1.0x.61m .44x.71x.40m	0.83 m^3 .88x1.0x.61m .88x.71x.40m	0.025 m^3 .48x.24x.21m
WEIGHT (maximum)	29 kg	45 kg	290 kg	580 kg	Stowage Dependent
POWER	28 VDC 5 amp max 110 W cont.	28 VDC 5 amp max 110 W cont.	28 VDC 35 amp limited	28 VDC 35 amp limited	5, 12 & 24 VDC 20W, 18W & 60W
ENVIRONMENTAL CONDITIONS					
PRESSURE	101.3 kPa	101.3 kPa	101.3 kPa	101.3 kPa	100.5 kPa
OXYGEN	25.9%	25.9%	21.7%	21.7%	21.7%
TEMPERATURE	18-35 °C	18-35 °C	10-35 °C	10-35 °C	18-35 °C
THERMAL CONTROL	Cabin Air	Cabin Air	Avionics Air Liquid cooling	Avionics Air Liquid cooling	Cabin Air
COMMAND & DATA MANAGEMENT	NONE	NONE	AVAILABLE*	AVAILABLE*	NONE
PHOTOGRAPHIC	AVAILABLE video, still	AVAILABLE video, still	AVAILABLE video, still	AVAILABLE video, still	AVAILABLE video, still
EXAMPLE	Space Acceleration Measurement System	Solid Surface Combustion Experiment (one module)		Surface Tension Driven Convection Experiment	Smoldering Combustion in Microgravity

* Commanding, monitoring, recording, processing & transmitting

TABLE 1 SUMMARY OF SPACE SHUTTLE / SPACE STATION ACCOMODATION RESOURCES

RESOURCE	GETAWAY SPECIAL (GAS) CANISTER	UNITED STATES MICROGRAVITY PAYLOAD	SPACE STATION FREEDOM
VOLUME	$0.14\ m^3$ .50 dia x .72 m	$1.75\ m^3$ .85x2.0x1.0m	$1.1\ m^3$
WEIGHT (maximum)	90 kg	308 kg	700 kg
POWER	Experiment supplied	28 VDC 470 W (865 W peak)	120 VDC
ENVIRONMENTAL CONDITIONS			
PRESSURE	Experiment specific normally 101.3 kPa	Zero unless experiment provided	70 - 101.3 kPa
OXYGEN	Experiment specific	None	21%
TEMPERATURE	-100 to 40 °C	-157 to 144 °C	20 - 30 °C
THERMAL CONTROL	Passive (Insulation)	Coldplate Available	Avionics Air Water Cooling
COMMAND & DATA MANAGEMENT	NONE	AVAILABLE*	AVAILABLE*
PHOTOGRAPHIC	NONE	NONE	
EXAMPLE	POOL BOILING EXPERIMENT	ISOTHERMAL DENDRITIC GROWTH EXPERIMENT	

* Commanding, monitoring, recording, processing & transmitting

References:

1. NSTS 21000-IDD-MDK Shuttle/Payload Interface Definition Document for Middeck Accommodations

2. SLP / 2104 Spacelab Accommodations Handbook

3. GET AWAY SPECIAL (GAS) Small Self-Contained Payloads Experimenter Handbook

4. MSFC-HDBK-527 / JSC 09604 Materials Selection List for Space Hardware Systems

5. SPACEHAB User's Handbook January 1991 prepared by McDonnell Douglas