Space-Based Test-Bed Concept

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This paper assesses the value to the development of advanced spacecraft bus technology of a space-based test bed (STB) and presents a conceptual design for one. The technical value and cost effectiveness of in-space testing have been demonstrated in past programs, and the STB concept would be the next logical step in space-based testing capability. Moreover, a review of the technical areas in which development will be required for the advancement of spacecraft bus technology clearly indicates the usefulness of the STB. Based upon the projected characteristics and support requirements of representative STB experiments, along with other design and operational needs, a versatile and cost-effective conceptual design for the STB has been developed. As envisioned, it is basically composed of a main spacecraft bus (whose subsystems provide the common support functions for the entire facility), and attachable/detachable experiment pallets. Its design requires relatively modest enhancements of current systems and techniques.

Introduction

THE concept of testing new technology capabilities in orbit is far from being a new idea, as some of the earliest spacecraft served as "hosts" for this very function. Included among these early spacecraft that were used for testing are Echos I and II, Telstar, and SYNCOM I–III, as well as several others. The first satellite series that was devoted to investigating new technologies was the Applications Technology Satellite (ATS) series that began in 1966 with the launch of ATS-1. The first five satellites in the series evolved directly from the earlier Advanced SYNCOM program; however, the new series was initiated to satisfy a need for higher efficiency and lower cost. The ATS experimentation began by investigating primarily communications technology (ATS-1 through ATS-5), but the last spacecraft in the series, ATS-6, incorporated a new design, allowing for an increase in the size and complexity of the experiment complement.[1,2]

Although the ATS program supplied valuable information in a large number of disciplines, it was not able to provide a "hands-on" inspection of hardware and materials exposed to the natural space environment over extended periods of time. Such testing generally requires onboard test equipment that historically has been too massive and required too much power to be feasible for use on small platforms. Therefore, the testing of exposure effects was limited to short-term on-orbit experiments and ground laboratory testing. This restriction ended in 1984 with the launching of the Long Duration Exposure Facility (LDEF).[3] LDEF was designed to accommodate 86 experiment trays, providing users with an economical and efficient method of testing a large number of items that would require modest power consumption and data processing while in orbit for extended stays. However, it has limited ability to record the time-variant characteristics of these environmental processes. Unfortunate delays in the retrieval of LDEF may well make some experiment results of less than intended value.

Coupled to these successes is the growing realization within the space community that the technology underpinnings of space exploration are an essential element of the future. Technology development and its subsequent testing must be pursued in order to make the promise of mankind's future in space a reality. Development of advanced technologies will require both ground-based and space-based testing of advanced technology concepts for spacecraft bus systems and components. There is a wide range in the types and purposes of tests to be performed in the space environment: 1) proof-testing of technological concepts, 2) testing and demonstration of new hardware, 3) qualification of spacecraft bus systems prior to their actual flight use, 4) determination of the performance of spacecraft bus systems, 5) verification of performance simulations (based on ground tests) and related scaling factors, and 6) materials testing.

The objective of an orbital spacecraft system test bed is to provide this testing capability. The ability to perform these tests in space is very important for several reasons. The primary reason is that certain conditions found in the space environment cannot be reproduced on the ground accurately enough, on a large enough scale, cheaply enough, or for long enough periods of time to provide meaningful or useful test results. A notable example of an area in which this is a concern is the exposure testing of materials in space for which samples are exposed to the combined effects of many environmental factors for an extended period of time.

Clearly, one of the largest benefits to be derived from an orbital test bed would be the expanded capability it would provide to perform a wide range of tests and experiments in space for extended periods of time, and to perform them at a reasonable cost. This capability also creates secondary benefits such as 1) reduction of the technical risk encountered when new technology is implemented, 2) motivation and stimulation of new technology development, and 3) increased commercial viability of future spacecraft. The test-bed concept can be considered complementary to the co-orbiting platform associated with the Space Station program. Unlike the co-orbiting platform and the Space Station itself, the orbital test bed is not meant to be sufficiently versatile to satisfy science, technology, and commercial interests, but rather is restricted solely to the interests of spacecraft system, subsystem, and component manufacturers. As a consequence, the permanent presence of man is not mandatory for mission success, and design simplicity of the supporting bus is paramount. Furthermore, the design approach for an orbital test bed must include the inherent need to protect data, an issue that can become very complicated on the Space Station. In addition, a test bed can potentially accommodate payloads that may present an unacceptable hazard to a manned system.

The space-based test bed (STB) concept discussed in this paper would provide the next logical extension in space experimentation platforms. It combines the proven and cost-effective method of "piggy-backing" experiments on a single

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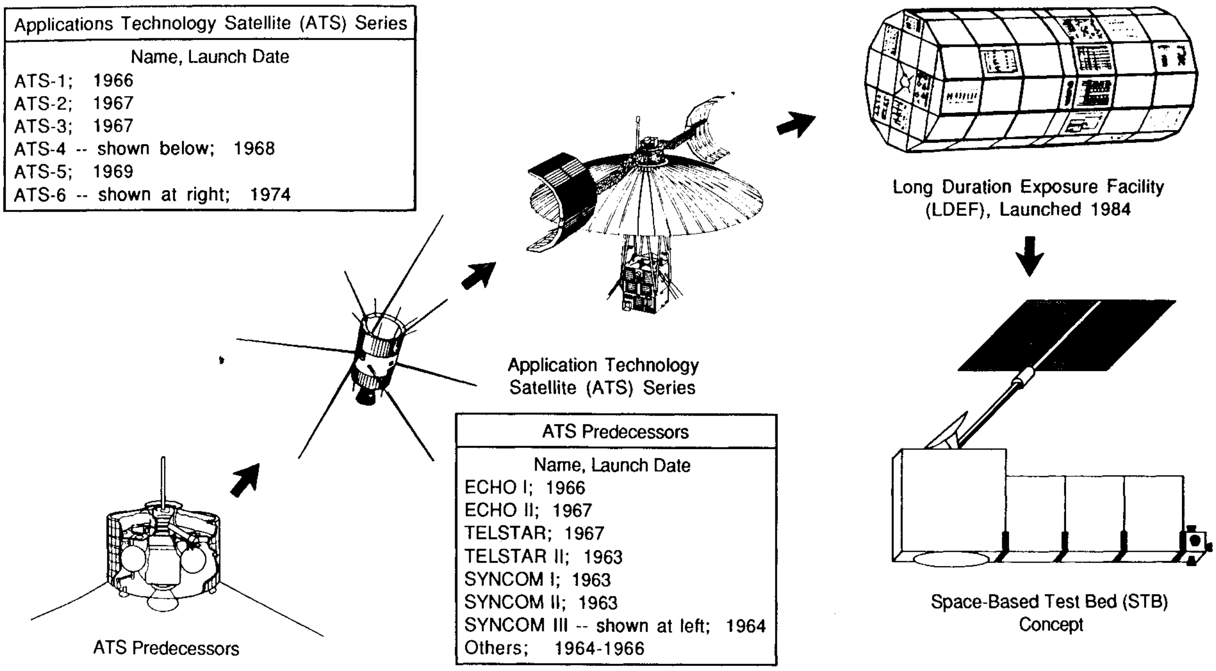

Fig. 1 Historical perspective of the STB concept.

Table 1 Summary of prioritized Spacecraft 2000 key technologies and their related testing needs

			Test beds				
			Space				
Subsystems working groups	Prioritized key technologies	Ground	STS		SS		FF
Spacecraft systems	1) Structural controls interaction	E					X
	2) Advanced thermal control	E	X	or	X	or	X
	3) Electric propulsion	E					X
	4) Nuclear power system	E & N					X
Propulsion	1) Advanced bipropellants	E					
	2) Electric propulsion	E & N					X
	3) Feed systems	E	X	or	X	or	X
Electrical power	1) High-voltage power systems	E	X	or	X	and	X
	2) Dynamic power systems (solar & nuclear)	E & N			?		X
	3) High-frequency power systems	E					X
	4) Advanced solar arrays	E	X	or	X	or	X
Thermal control	1) Advanced heat pipes	E	X	or	X	or	X
	2) Advanced fluid heat-transfer systems	E & N			X	or	X
	3) Advanced passive thermal control systems	E			X	or	X
TT & C/Comm	1) Microwave components	E	X	or	X	or	X
	2) Low-cost test techniques	E					
Data management	1) Fault tolerance	E					
	2) 10 MOPS speed	E					
	3) Higher speed data transmission	E					
	4) Onboard data storage	E			X	or	X
Attitude control	1) ACS validation and test	E & N					X
	2) Flexible structure control	E & N					X
	3) ACS Autonomy	E					?
	4) Low-noise sensors and actuators	E					X
Structures & materials	1) Advanced materials & characteristics	E					X
	2) Test/qualification/verification methods	E & N					X
	3) Zero-gravity operations (assembly, processing, joints/connectors)						
Telerobotics	1) Zero-*g* manipulation	E	X	or	X		
	2) System performance validation	E	X	or	X		
	3) S/C 2000 test-bed facilitator	E					X

Note: STS = Space Transportation System; SS = Space Station; FF = Free-Flyer; E = Existing; N = New.

Table 2 General characteristics of representative in-space experiments and tests

Spacecraft system experiments (typical), tests, etc.	Mass, kg	Size, m $W \times L \times H$	Required power, W	Data needs: Transfer rate, Mbps	Data needs: Storage, gigabits	Comments
Propulsion systems	75–500	$2 \times 6 \times 2$	$\leqslant 1500$	≈ 1	≈ 1	Includes: test facility for low-thrust systems; propellant reliquifaction test apparatus; plume characterization with mass spectrometer on mobile arm.
Thermal control	50–200	$1 \times 1.5 \times 2$	$\leqslant 3000$	$\leqslant 1$	$\leqslant 2$	Includes: two-phase fluid test apparatus; two-phase fluid systems multiple experiment rack. Electricity could be saved by using another heat source.
Energy systems	<300	$1 \times 0.7 \times 0.6$	$\leqslant 2000$	Low	Low	Apparatus for electrolysis of water (used for energy storage).
Navigation systems	50	$2 \times 0.4 \times 0.4$	$\leqslant 1000$	0.3	1	Laser tracking interferometer/CCD array signal processing system for spacecraft tracking.
Materials	10–200	$0.7 \times 0.5 \times 0.3$	100–1000	0.001	0.5	Includes: apparatus for measuring long-term effects of space environment on material samples; apparatus for measuring these effects on polymeric materials with tribological uses.
Attitude control systems	1400	1.5×1, diam	300	0.06	0.2	Advanced experiment pointing and isolation device.

bus, as was done in the ATS series, with the extended stay and retrievability capabilities that were designed into the LDEF platform. In addition, the STB is designed to be modular, thus enabling on-orbit experiment package changeout and simple servicing. It can also be returned to Earth as a complete unit, allowing refurbishment and re-use with a rapid turnaround, and maximizing its in-space operation and data return. The historical evolution of space-based testing to date is summarized in Fig. 1.

Space-Based Testing Needs and Requirements

As a first step in the formulation of a conceptual design for the STB, a list of potential space-based system testing needs must be assembled. This list can be derived from the recommendations for in-space testing of advanced spacecraft bus systems and technology made by the subsystems working groups at the "Spacecraft 2000 Workshop."[4] Before discussing possible test-bed experiment requirements in detail, however, a summary of Spacecraft 2000 key technologies and their related testing needs will be presented in order to emphasize the overall usefulness and value of the STB in a broad range of technology development areas.

In Table 1, the most important key technologies identified by each of the Spacecraft 2000 working groups are listed in priority order.[5] Along with the key technology list, Table 1 summarizes the results of a top-level analysis of the ground and in-space testing needs related to these key technologies. Also indicated is whether the ground-test capability for each technology exists or would be new, and whether or not the related in-space test requirements could be met by the major capabilities of the Shuttle, the Space Station, or a free-flying test bed.

Although the workshop recommendations are detailed enough to call for specific types of tests for some areas of technological development, they do not provide specific information about experiment sizes and weights, or power and other particular test support requirements. In order to estimate the sizes and support requirements of the kinds of experiments that might be placed on the STB, additional and more detailed information about potential in-space tests was required. The information most closely matching this need can be culled from the proceedings of the In-Space Research, Technology and Engineering (RT&E) Workshop.[6]

Table 3 Projected mass summary for the STB spacecraft bus and its subsystems

Subsystem	Mass, kg
Structure	1350
Communications	50
Data storage/handling	130
Attitude control	80
Power	540
Thermal control	60
Propulsion (dry)	140
Total	2350

Experiments that were close matches to the type and size of experiments to be performed onboard the STB were identified and grouped according to their general technology area (e.g., propulsion, thermal control, materials, etc.). The characteristics (mass, power, size, and so forth) of each individual experiment were combined with those of the other experiments in its respective general technology group, thus providing representative ranges for experiment characteristics. The results of this analysis are presented in Table 2. This information provides a reasonable "ballpark" estimate of the characteristics and requirements of a large range of potential STB-borne experiments. These estimates were used to size the STB and to formulate its conceptual design. The general conclusions derived from this information were that the maximum power to be provided to experiments would be 2 kW, and that individual experiment masses and sizes would be such that they could easily be placed on pallets.

STB Conceptual Design

It was assumed that cost would be a major driver in the STB design and operation. To accommodate this condition from a design standpoint, an active effort was made to keep the STB design as small and as simple as possible, while still

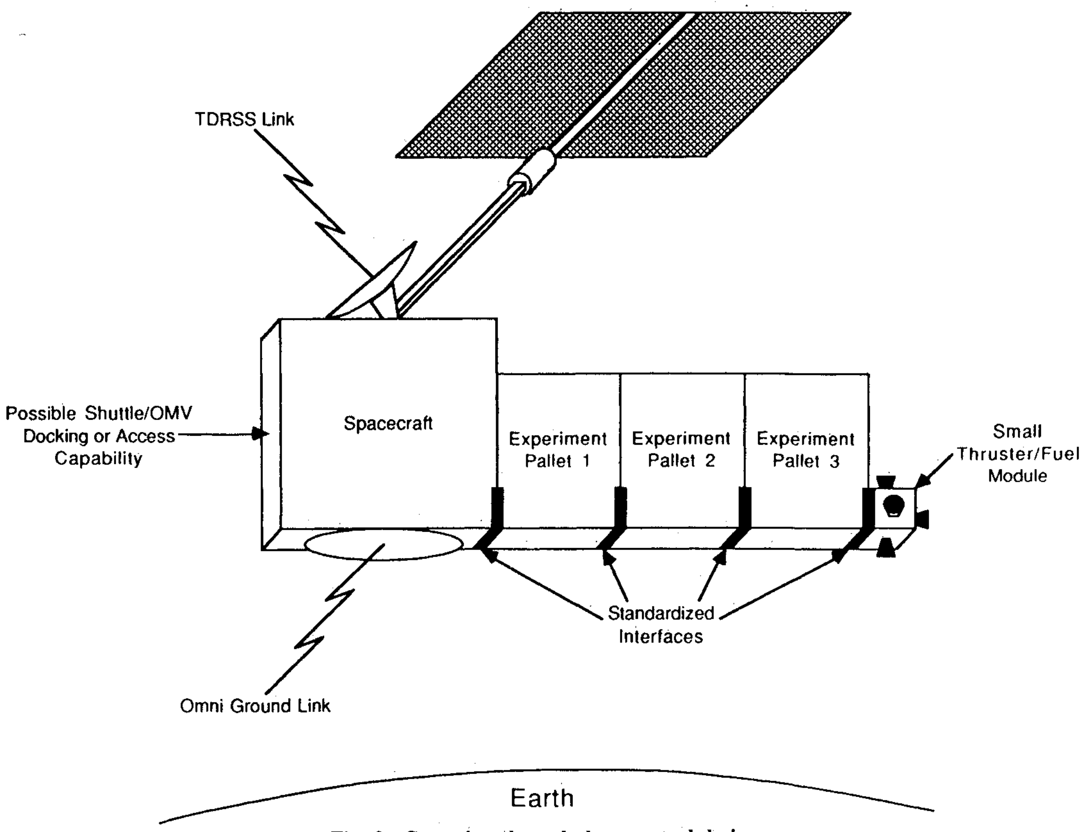

Fig. 2 Space-based test-bed conceptual design.

making it sufficiently large and versatile to permit significant and useful testing. An effort was also made to use "off-the-shelf" systems and technology whenever possible. When existing systems and technology were not adequate, however, an effort was made to use the appropriate systems and technology that are modest extensions of current practices.

As envisioned, the STB is composed of a main spacecraft bus and attachable/detachable experiment pallets.[7] The spacecraft bus is essentially a super "Explorer"-class spacecraft, with an estimated dry mass of approximately 2350 kg, and its subsystems are intended to provide the common support functions required by the STB and its onboard experiments. (Table 3 contains a more detailed mass breakdown for the spacecraft bus and its subsystems.) Individual experiment pallets (each with one or more experiments) are attached to the spacecraft bus and to other pallets by standardized, smart interfaces. Each pallet has an estimated mass of approximately 1000 kg and a load capacity of approximately 2270 kg. The interfaces provide rigid mechanical connections and electrical, telemetric, and thermal connections. In addition to individual experiments, it may also be possible to test a completely integrated advanced technology spacecraft bus in orbit by connecting it to the STB bus with a standardized interface. Provisions have also been made for the use of an optional, attachable/detachable thruster/fuel module.

There are a variety of possible bus-pallet arrangements that could be used. However, in the process of formulating the STB conceptual design, one configuration evolved that appeared to be especially attractive. It is pictured schematically in Fig. 2. The two main advantages of this particular configuration are that all of the experiment pallets are placed on the same side of the spacecraft bus, and that the opposite side is left clear for docking or access to the spacecraft subsystems. Placing the pallets on the same side of the spacecraft results in fewer interfaces (and associated internal subsystem connections) on the spacecraft itself, simplifying and compacting its internal and external structure. Keeping the other side of the spacecraft clear of pallets, antennas, and other obstructions, provides a convenient place to attach hardware for grappling with the Shuttle's rms arm, or docking with an Orbital Maneuvering Vehicle (OMV) from the Space Station. It also provides excellent access to the spacecraft subsystems for maintenance, repair, replacement, and fluid replenishment. (This aspect is especially attractive if modular construction is used.) Designing the STB with this clear side and the experiment pallets on opposite sides of the spacecraft places the docking and grappling activities as far away from the onboard experiments as possible, where they are least likely to endanger any experiments.

The STB is three-axis stabilized to allow precise orientation and pointing control for each experiment and to allow easy access by, or docking with, the Shuttle or OMV for emplacement, servicing, or reconfiguration. The experiments placed onboard will be capable of autonomous and ground control. The STB is expected to be placed in an orbit with an altitude of approximately 400 km (approximately 220 n.mi.), corresponding to the Space Station altitude.

As currently envisioned, the most probable operational scenario for the STB calls for the spacecraft bus and its initial complement of experiments to be launched into orbit by the Shuttle. (The STB bus and four experiment pallets will fill the cargo bay.) When an onboard experiment pallet is to be removed or when a new pallet is to be attached, the necessary mate/demate processes will be performed while the STB remains in orbit. Although it is possible to retrieve the full STB for ground-based pallet changeouts and then to relaunch it back into orbit, it is expected to be significantly more cost-effective to perform pallet changeouts in orbit. Routine STB servicing (repairs, component replacements, fluid replenishments, etc.) will also be performed in orbit. Although changeout and servicing operations will probably be performed with the Shuttle, it may be desirable to retrieve the STB with an OMV and to transport it to the Space Station for these operations.

The STB has a nominal design life of five years. Although it could be designed to operate for a longer period of time (ten years, for example), that would require a larger solar array to meet the end-of-life (EOL) power requirement and probably would require more initial development—both raising the initial program cost. Five years represents a good compromise between longevity and initial cost.

STB Bus Power

Power is a key design driver for the STB.[8] The STB power subsystem is sized to produce an EOL electrical power of 2.5 kW. (A solar array with an estimated area of approximately 24.2 square miles, producing a beginning-of-life (BOL) electrical power of approximately 3.13 kW, is required to provide this EOL capacity.) It is estimated that approximately 0.5 kW will be required to support the spacecraft bus subsystems, leaving approximately 2 kW available to supply all of the onboard experiments. The power subsystem design uses a deployable/retractable, mast-mounted solar array and secondary batteries (probably Ni-H_2). Although generally beyond current typical unmanned spacecraft performance, such a system well is within the realm of technical possibility.

The total power to be provided to all the onboard experiments was estimated from the information on representative experiments shown in Table 2.[9] The 2-kW power level was chosen as a reasonable balance point between using available technology and satisfying the power needs of the majority of possible experiments. Certainly, many of the smaller experiments can be run simultaneously at this level. Furthermore, many experiments will not require power all the time. This will allow their operation to be scheduled to optimize the number of experiments on the STB. Moreover, some energy-intensive experiments may be redesigned to eliminate their most energy-intensive components. (As one example, electrical heat sources in thermal control system experiments may be replaced with solar heat sources.) Power considerations will be a major driver in designing, manifesting, and operating experiments to be placed on the STB.

Data and Communication Subsystems

The STB is designed to use a packetized data system. In such a system, a main computer, located on the spacecraft bus, communicates with all of the experiments on the STB through a main data bus and smart interface units at each of the spacecraft-pallet and pallet-pallet standardized interfaces. The data bus operates at 1 to 2 Mbps. All experiments, through similar smart interface units, have access to all of the bus data flow, assuring access to all of the information that each needs to operate. It should be noted that these are the same data bus architectures and data rates as those being proposed for use with the PROTEUS spacecraft concept and the Explorer Platform.[10–12]

The main spacecraft computer handles all of the STB bus subsystems, including communications and power distribution. All of the computing needs specific to each experiment are handled by the necessary hardware built into the experiment itself, or into its respective pallet. This hardware is connected to the data bus through smart interface units, as described before. Up to 10 Gbits of data storage capacity are provided by a tape recorder on the spacecraft bus.

For communications, the spacecraft bus is equipped with a Tracking and Data Relay Satellite (TDRS) link operating at 1 Mbps, and an omni ground link operating at 50 kbps. The TDRS link handles the experiment-related telemetry traffic, and the ground link handles the spacecraft bus operations support.

Standardized Interfaces and Related Experiment Support Subsystems

As noted, standardized interfaces are used to connect a pallet to the side of the spacecraft bus and to connect one pallet to another pallet. One is located on the side of the spacecraft bus and at both ends of each pallet, allowing pallets to be strung together from the side of the spacecraft bus while maintaining all of the necessary connections between the bus and the experiments. The design of these standardized interfaces is another key STB design driver.[13] They must be simple to make and to mate/demate, and they must be smart. The rigid mechanical connections they provide enhance structural strength and rigidity for the entire STB structure, creating a stable experiment platform. In addition, they also provide electrical, telemetric, and thermal connections between adjoining units.

The electrical connections provided by the standardized interfaces allow power to be transmitted from the power subsystem to each experiment. The interface on the side of the spacecraft bus connects all of the attached experiment pallets to the power subsystem. On each pallet, the electrical distribution system connected to the interfaces provides two functions. It supplies the necessary electrical power to the experiments on the pallet and also provides pass-through circuits, allowing electrical power to simply pass through the pallet to supply pallets connected to its outboard side. Smart control units contained in the interfaces permit the spacecraft bus main computer to control the power distribution through this system of connections and possible circuits. Abundant built-in connections and wires, along with the computer's circuit switching capability, provide redundancy in the event of power circuit failures, and power distribution flexibility for easily accommodating the removal and addition of experiment pallets.

Smart interface units are also incorporated into the standardized interfaces (one in each half) to provide access by each experiment to the STB data bus. The interface on the side of the spacecraft bus connects the attached pallets to the spacecraft's main computer. The interfaces on each pallet provide access to the main data bus by all of the experiments on a pallet and by the pallets attached to its outboard side. As mentioned before, all of the computing and automation needs

STRUCTURE	PALLET + PAYLOAD INTEGRATION EQUIPMENT
SUBSYSTEMS	SMART FLEXIBLE MULTIPLEXER/DEMULTIPLEXER MULTIPLEXER RECORDER
CAPABILITY (AVAILABLE TO PAYLOADS)	
NO. OF EXPTS	MULTIPLE
LOAD	2268 KG (5000 LBS)
POWER	1200W
DATA	48MBS
CONTROL	PAYLOAD OPS CONTROL CENTER/ AFT FLIGHT DECK OF ORBITER
LENGTH IN BAY	2.875 M (113 INCHES)
OPTIONAL SERVICES	YES
ADDITIONAL INFORMATION	HQ/ML/RX LaRC/153
AVAILABILITY	1988

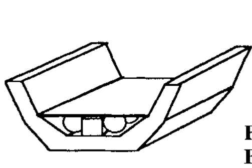

Fig. 3 Characteristics of the Space Technology Experiment Pallet (STEP).

specific to each experiment are handled by the necessary hardware built into the experiment itself or into its respective pallet. This hardware is connected to the data bus through a smart interface unit.

The thermal contacts at each interface are cold plates. The contact on the spacecraft bus connects the experiment pallets to the spacecraft's thermal control subsystem. On each pallet, the thermal control subsystem connected to the interfaces provides two functions. It connects the pallet's experiments (when necessary) to the spacecraft bus thermal control subsystem, and also provides a pass-through segment, allowing outboard pallets to be connected to the bus thermal control subsystem. Most probably, heat pipes will carry excess heat from the experiments to the inboard cold plate and from the outboard cold plate (connected to outboard pallets) to the inboard cold plate.

STB Bus Thermal Control

Although the size and design of the spacecraft bus thermal control subsystem have not been addressed in detail, some of its general characteristics can be discussed. This subsystem is expected to handle all of the thermal control needs of the spacecraft bus and any of the attached experiments, which may also require outside thermal control. It is intended that, whenever possible, experiments should be designed with the capability to manage their own thermal control. However, this may not always be possible, and the spacecraft bus thermal control subsystem should be sized and designed to handle the projected thermal control needs of potential STB-based experiments and those of the spacecraft bus.

Before the thermal control subsystem can be designed in detail, potential STB-based experiments will have to be designed and their thermal control needs determined. At this point, it seems that the most probable subsystem design will involve the use of heat pipes in conjunction with radiator panels. However, alternative designs, using liquid coolant loops or other types of systems, may be necessary.

Experiment Pallet Structure and Capacity

The experiment pallet is envisioned generally as a structure very much like the Shuttle cargo pallet with additional experiment support hardware (described previously) built into it. More specifically, it could very well be designed and built as a modified version of the Space Technology Experiment Pallet (STEP).[14,15] As the specifications for the STEP (given in Fig. 3) indicate, perhaps relatively minor modifications and additions could be made to make it suitable for this application.

The load capacity for the STEP is approximately 2270 kg (5000 lb). Since all but one of the representative experiments listed in Table 2 have masses of 500 kg or less, it is quite possible for a pallet to carry more than one experiment. The major limitations to the number of experiments placed on a single pallet are the volume each experiment requires to operate properly, concerns about interference or contamination from neighboring experiments, and thermal control requirements. The mass of a pallet (without experiments, but with all of its support subsystems) is estimated to be approximately 1000 kg, and its internal dimensions are approximately 3.8 m wide × 2.9 m long.

Optional Features

After several experiment pallets have been attached to the STB, it may be necessary, or at least desirable, to attach additional thrusters and fuel to the outboard side of the outermost pallet (as shown in Fig. 2). This would increase attitude control authority and extend the stationkeeping lifetime between refuelings, and could be accomplished easily by using an attachable/detachable thruster/fuel module.

This module would contain a set of standard, small, maneuvering thrusters, a supply of thruster fuel, and a standardized interface for connecting it to the STB. As with all of the other standardized interfaces on the STB, this one would provide a strong, rigid, mechanical connection along with electrical and telemetric connections. Thruster firings would be controlled by the main spacecraft bus computer. It is assumed that no active cold plate on the module interface would be necessary to remove excess heat; however, an active heat-transfer system could be built into the module if necessary. It may also be necessary to design some thruster shielding into the module to protect experiments on the closest pallet from possible plume contamination.

The thruster/fuel module could also provide other useful functions. For example, it could be used to change the STB orbit or, otherwise, translate it in space for rendezvous with the Shuttle or Space Station. However, all issues relating to the use and design of this module cannot be adequately resolved until more detailed work has been done in designing the STB and its experiments, and in determining the specifics of its operation.

The use of easily replaceable modular spacecraft subsystems would expand the STB's versatility and extend its operational life. There may be value in designing the spacecraft around the Multimission Modular Spacecraft (MMS) series of subsystem modules.[16] In addition, making the spacecraft bus propulsion system replenishable would also go a long way in extending the STB's operational life between required retrievals. However, the design of such systems would require the modification of off-the-shell hardware. Further trade studies will be required to determine whether it is more cost effective to use as close to off-the-shell systems as possible or to develop more flexible systems.

STB vs Alternatives

Now that the need for in-space testing has been established and a conceptual design for a space-based test bed proposed as an efficient and logical means by which to satisfy this need, the relative value of using the STB over the other alternatives will be discussed. The alternative that comes closest to providing in-space testing capabilities similar to those of the STB for the least cost (and one that has already been demonstrated in space) is an ATS-type spacecraft. It is clear from the previous discussions that the STB offers considerably more testing versatility than an ATS-type spacecraft, but how do their costs compare?

Using an available spacecraft cost model, the first-unit STB costs in 1986 dollars (including only design, development, test and evaluation, hardware production, and associated program-level costs) were estimated to be approximately $81.5 million for the spacecraft bus alone and $4.7 million for each experiment pallet.[17] (It should be noted that a production of one spacecraft bus and four pallets was assumed, and that most of the development cost for the standardized interface is contained in the cost of the pallets.) As a point of comparison, similar costs for the ATS-2 satellite totaled $90.52 million (in 1986 dollars). (ATS-2, like the STB, was a single-production satellite buy.)

This cost comparison is quite compelling. The fact that the projected cost of building the STB is so close to that of an ATS satellite makes the STB a very attractive and cost-effective way to perform sophisticated testing in space. Moreover, since the STB is designed to accommodate much larger and more complex experiments than the ATS satellites, and to allow experiment changeouts throughout its five-year lifetime, its relative overall benefit-to-cost ratio should be considerably better.

Summary

Improving the technological underpinnings of space exploration is an essential element of mankind's future use of space. The development of advanced spacecraft bus system technology is particularly critical. A review of the technological development needs and requirements that are key to the development of advanced spacecraft bus technology shows that there is a clear and definable need for a space-based test bed. Past U.S. satellite-based on-orbit test programs have demonstrated the value and cost-effectiveness of such testing, and the STB concept is the next logical step in the long-established advancement of on-orbit testing capabilities.

The objective of the STB is to provide a versatile and cost-effective in-space testing capability, facilitating the introduction of advanced technology into spacecraft bus systems without increasing program risk. The primary benefit of the STB would be the expanded capability it would provide to cost-effectively perform a variety of tests and experiments in the space environment for extended periods of time. This capability would reduce technological risk when implementing new technology, stimulate new technology development, and increase the commercial viability of future spacecraft.

Overall, the STB conceptual design would require relatively modest enhancements of current systems and techniques. It was formulated around the desire to use as close to off-the-shelf technology and hardware as possible. Many of its proposed systems already exist or could be made by upgrading existing systems. The development of new systems should be aided substantially by the development efforts planned for other missions and programs.

Acknowledgments

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[17] Dodson, E. N., "Technological Change and Cost Analysis of High-Technology Systems," *IEEE Transactions on Engineering Management*, Inst. of Electrical and Electronics Engineers, New York, May 1977.