



Apr 27th, 1:00 PM - 4:00 PM

Paper Session II-A - ISOBUS A Faster, Better, Cheaper Tool for Space Flight Experiments

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ISOBUS

A "Faster-Better-Cheaper" Tool for Space Investigators

presented at
31st Space Congress
Commercial Utilization Session

April 26-29, 1994
Cocoa Beach, FL 32932

by

David Tamir

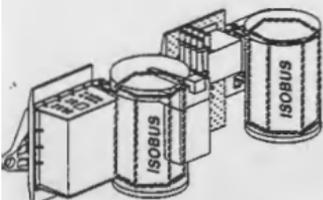
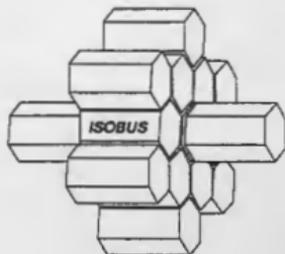
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JPL — **Rockwell** —
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ABSTRACT

This paper describes a "faster-better-cheaper" concept for diverse space experiments and applications. The concept, called ISOBUS, is a modular universal platform which offers the space investigator a suite of various off-the-shelf accessories and utility services. An ISOBUS platform provides the investigator standardized support structure, power, control, data recording, and other optional subsystems. An ISOBUS platform can serve Space Shuttle cargo-bay experiments, Space Station EXPRESS attached experiments, and low Earth orbit (LEO), near-Earth, Lunar, and interplanetary spacecraft experiments. An ISOBUS platform is made of one or several interconnected modules. Each module is sized to fit in a Get Away Special (GAS) canister and have the characteristics of a Shuttle payload line replaceable unit (LRU) and a spacecraft orbital replacement unit (ORU) with mechanical, electrical, and fluid quick-connect / disconnect and blind-mate / de-mate interfaces. GAS canisters can house and transport the ISOBUS modules to LEO as Shuttle Small Payloads. Upon arrival at LEO, ISOBUS modules may remain in their respective GAS canisters, or be removed from them using the Shuttle's Remote Manipulator System (RMS) with the Dexterous End Effector (DEE). A single ISOBUS module extracted from a GAS canister can be deployed for mini-sat applications or be attached to the Space Station. Moreover, several extracted ISOBUS modules can be interconnected into a spacecraft assembly capable of LEO, near-Earth and interplanetary missions.

INTRODUCTION

Space exploration and related investigations have been suffering from programmatic inefficiencies inherent to customized projects. "One-of-a-kind" space investigations such as experiments, installations, platforms, and missions all lack the profit-driven architectures and money-making methodologies that characterize commercial enterprise. The foundation of long-term commercial success is in the smart and efficient utilization of capital investment. An enterprise that throws away its tools, its infrastructure, its expertise, and its capital, every time it completes a project is not likely to be able to afford to do so again and again. When resources are scarce, one must utilize them efficiently. Proven commercial methodologies such as standardization, mass production, miniaturization, modular interchangeability, and reusability of tools, facilities, and resources are the principal techniques by which products can be created "faster-better-cheaper." Commercial investigators in intensely competitive fields, such as biotechnology, have successfully applied these principles to their experimental setups, tools, and support systems. We must similarly employ commercial principles if we are to survive the expensive challenge of future space exploration. This paper introduces a "faster-better-cheaper" approach for space investigators. The approach employs a tool called ISOBUS.

DEFINITIONS

ISO stands for standardized, uniform, modular parts. **BUS** stands for a universal platform / carrier. **ISO-BUS** then is a standardized, modular, universal platform for carrying diverse space experiments and applications. **ISOBUS** takes the form of a payload bus or a spacecraft bus made of one or several hexagon-shaped modules. **ISOBUS** is a payload during its transportation phase to low Earth orbit (LEO) on the Shuttle. Once on orbit, **ISOBUS** may remain a Shuttle payload in the cargo bay, or it may be attached to Space Station, becoming a Station EXPRESS payload, or it may be deployed to become a free flying spacecraft.

A single **ISOBUS Module** is designed to fit in a Shuttle cargo bay Get Away Special (GAS) canister (see Figure-1). An **ISOBUS Module** is designed with Shuttle Line Replaceable Unit (LRU) and spacecraft Orbital Replacement Unit (ORU) characteristics. These characteristics allow the **ISOBUS Module** to be inserted easily and quickly into a Shuttle payload carrier, such as the GAS canister, and into a spacecraft such as Space Station. The LRU/ORU characteristics also allow easy and quick module removal and replacement. The LRU/ORU characteristics are created primarily by standardized mechanical, electrical, and fluid interfaces with quick-connect / disconnect, blind-mate / de-mate features. Moreover, these standardized interfaces allow several **ISOBUS Modules** to be interconnected on-orbit into an **ISOBUS Cluster** (see Figure-2).

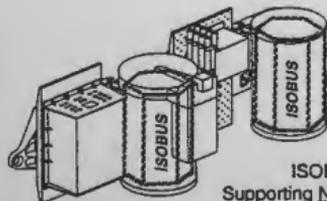


Figure-1:
ISOBUS Modules
Supporting Non-Deployed
Experiments Contained in GAS Canisters
Mounted to Shuttle Cargo Bay Sidewall

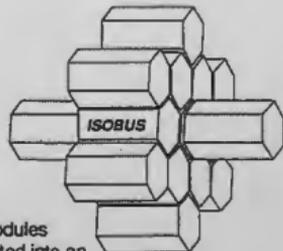


Figure-2:
Deployed
ISOBUS Modules
Interconnected into an
ISOBUS Cluster Spacecraft Configuration

NEED FOR ISOBUS

Space investigators need "faster-better-cheaper" tools to access space. Today, most investigators sacrifice time, reliability, and money while "reinventing the wheel" of structure, power, control, data recording, and various other utility subsystems required to support space investigations. ISOBUS strives to eliminate this most serious inefficiency through the provision of an off-the-shelf, reusable, standardized experiment bus with proven utility subsystems. The ISOBUS subsystems are modular in design, enabling continued utilization of the latest state-of-the-art technologies.

A good example illustrating the need for ISOBUS is the GAS program. The GAS program was developed by NASA to help investigators access space more quickly and cost effectively than with other Shuttle payload programs. The GAS program provides a standardized container (see Figure-3) with three simple on-off commands executable from the Shuttle's Aft Flight Deck. A significantly reduced ticket price to fly and a more user friendly flight certification process are the two primary incentives to GAS users. With approximately 100 flown payloads over 12 years and over 300 individual experiments (as of early 1994), the GAS program is an asset to be applauded. However, hundreds of purchased GAS flight reservations are currently sitting inactive. In addition, lately GAS flight reservations have been increasingly substituted with "lead-ballast" due to lower than expected investigator turnout. Why? The problem is not the lack of worthwhile investigations, but the slow turnaround time, high risk of failure, and high expense associated with preparing "one-of-a-kind" investigations for flight. GAS users have sacrificed time, reliability, and money developing custom structure, power, control, data recording, and various other utility subsystems required to support their individual experiments. Rather than focus most of their energies on the investigations at hand, GAS users keep wrestling with utility subsystems. Consequently, utility subsystems can leave little funding and volume for the mission instruments. It is true, however, that for educational institutions it is desirable to put engineering students through the difficult path of reinventing such utility subsystems. But, for the commercial investigator such reinvention is wasteful. ISOBUS proposes to offer leasing of off-the-shelf reusable utility subsystems, which have already been certified and flight proven, hence reducing development time and cost and increasing reliability. Another problem which discourages investigators, is the two to three month unattended sit-time for GAS experiments prior to launch. This sit time proves to be too long for various perishable specimens (e.g., biological) and systems (e.g., rechargeable batteries). The sit time is

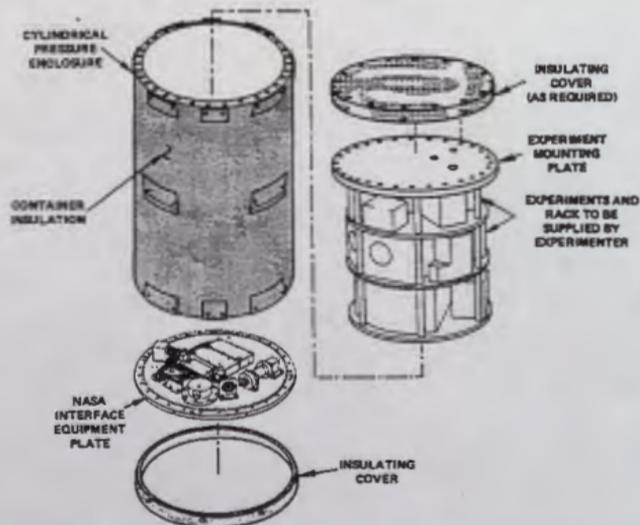


Figure-3: Get Away Special (GAS) Payload Accommodations

driven by payload processing constraints associated with pre-integration of the investigator's package into the GAS canister off-line, prior to the canister's installation in the Shuttle. ISOBUS, on the other hand, enables late-pad installation (a couple of days prior to launch) of LRU-like investigator packages into pre-mounted GAS canisters, hence almost eliminating sit time. ISOBUS offers these and other enhancements to assist the space investigator in circumventing chronic inefficiencies which will likely continue to plague programs such as GAS and the upcoming Space Station EXPRESS attached payloads program.

ISOBUS offers inter-compatibility between the Shuttle GAS / Hitchhiker-type and the upcoming Station attached EXPRESS-type payload accommodations. This will provide the flexibility to switch from Shuttle-based investigation to Station-based without having to spend additional time and money re-configuring the experiment hardware. Shuttle flight opportunities may prove too short or too "noisy" (induced vibration) for satisfactory results. Hence, Station may become a better alternative. On the other hand, Station operations may become delayed or too limited to support a timely experiment. Hence, Shuttle flight (e.g., Extended or Long Duration Orbiter) may be a satisfactory alternative. In either case, inter-compatibility between Shuttle and Station experiment accommodations will prove essential to fostering cost-effective space-based investigations.

Shuttle- and Station-based payloads serve the community of space investigators, but they do not satisfy all of the community's needs. Investigation of remote environments or objects such as Earth polar orbits, near-Earth and interplanetary space, the Moon and other planets usually require mission-dedicated spacecraft. The traditional size, complexity, and high cost (1 - \$2 billion) of such probes (e.g., Galileo) is limiting the number of missions and corresponding researchers, students, and professionals who can actually "do" space investigations. With the growing costs of Earthbound social programs, expensive customized spacecraft can no longer be justified. Consequently, NASA's new Discovery and Explorer Programs have been mandated to stimulate and develop small space exploration missions which can be accomplished by the academic and industry research communities. Discovery missions, for example, are targeting goals of maximum three year preparation to launch with no more than \$150 million. But, even these goals may soon prove to be too expensive. ISOBUS, on the other hand, offers a new "faster-better-cheaper" approach to spacecraft design. It's based on mass production and utilization of standardized, off-the-shelf, modular, subsystem building blocks. ISOBUS promises more practical and cost-effective means of launching such spacecraft with on-orbit assembly and checkout, using Shuttle small payload carriers (e.g., GAS canisters) and the Shuttle Remote Manipulator System (RMS).

ISOBUS CONCEPT DEVELOPMENT

Development of the ISOBUS concept is based on work accomplished by Utah State University's Space Dynamics Laboratory (USU/SDL), California Institute of Technology's Jet Propulsion Laboratory (JPL), and Rockwell International Corporation's Space Systems Division (Rockwell SSD).

USU/SDL has been world prominent in performing GAS-type experiments since the inception of the GAS program. USU developed the first GAS experiment and various others. They played a key role in the development of the first GAS-deployed miniature-satellite (minisat), named NUSAT (see Figure-4). They have performed extensive research and develop-

ment of small payload / spacecraft bus structures and matured the use of Isogrid design and production practices in conjunction with JPL. USU has developed a modular GAS experiment rack known as ISOSPACEPAK and a minispacecraft structure known as ISOSAT. Today, USU/SDL is trying to reestablish the use of GAS-deployed mini-sats.

In conjunction with industry, JPL is developing several minispacecraft for solar system exploration (e.g., Pluto Fast-Flyby, Mars series). Looking beyond these, JPL is also undertaking a microspacecraft development program aiming to produce more aggressively-miniaturized, cost-effective, advanced technology spacecraft for near-Earth and interplanetary exploration missions.

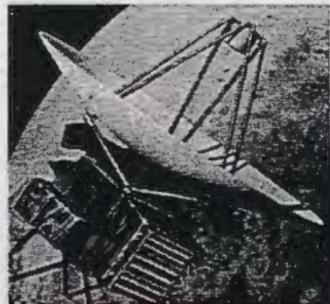


Figure-5: Small Pluto Fast-Flyby Spacecraft (early '93 configuration)

Rockwell SSD is pursuing increased and enhanced utilization of the Shuttle system (see Figure-6). This includes "faster-better-cheaper" means for Shuttle and Space Station payload investigations and Shuttle-deployed free-flying investigations (e.g., mini-sats and small planetary probes). Based on experience with GAS investigations and Shuttle cargo integration, Rockwell SSD is studying a number of advanced small payload concepts including ISOBUS. The Rockwell ISOBUS concept draws heavily on USU/SDL and JPL's work. In addition, Rockwell SSD is studying on-orbit deployment (manipulation, transfer to Station, release) of ISOBUS Modules using the Shuttle's Remote Manipulator Systems (RMS) in conjunction with upcoming advanced on-orbit robotic manipulators and end-effectors.

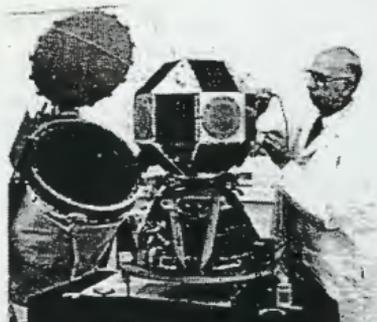


Figure-4: NUSAT
First GAS Deployed Mini-Sat

USU/SDL produced a prototype 7-kg spacecraft bus structure for the Pluto Fast-Flyby mission, which is under advanced development at JPL (see Figure-5). USU/SDL is basing the spacecraft bus structure on their ISOSAT and Isogrid experience. JPL is also contracting USU/SDL for prototype 5-kg Isogrid microspacecraft structures. Besides spacecraft missions, JPL is also involved with the In-Space Technology Experiments Program (In-STEP). JPL is pursuing various experiments, some of which employ Shuttle Small Payloads (e.g., GAS canisters). Consequently, JPL is interested in more cost effective tools for conducting both planetary exploration missions and Shuttle-based investigations.

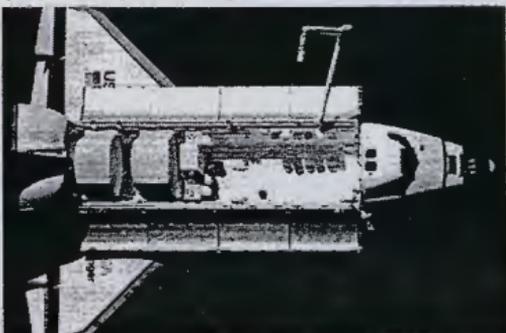


Figure-6: Rockwell is Pursuing Faster-Better-Cheaper Utilization of Shuttle by Space Investigators

NASA Johnson Space Center (JSC) and JPL have recently (early 1994) successfully demonstrated on-orbit a modular end-effector for the Shuttle's RMS (see Figure-7). This new system achieves increased dexterity and alignment accuracy of the RMS by incorporating a Magnetic End Effector (MEE), a Force Torque Sensor (FTS), and a Targeting and Reflective Alignment Concept (TRAC). The modular MEE is transported in the Shuttle's cargo-bay independently of the RMS using a Carrier Latch Assembly. Once on-orbit, the RMS is manipulated to grapple the MEE from its Carrier Latch Assembly mount. Teleoperation of the MEE with the FTS and TRAC is achieved from the Aft Flight Deck with the on-board Closed Circuit Television. This new RMS system is called the Dexterous End Effector (DEE). The RMS-DEE combination allow practical on-orbit deployment of smaller payloads; because the penalty of mass and volume imposed by the RMS Grapple Fixture interface is eliminated by the relatively minor interface required by the DEE. The DEE only requires an interface made of a Permadyne (a ferrous alloy) plate, 12 inches in diameter, and 0.5 to 1 inch thickness (depending on required grappling force). Consequently, upcoming advanced robotic manipulators and end-effectors such as DEE will enable exciting deployable applications with ISOBUS Modules, such as: mini-sat releases, attachment of experiments to Space Station, and even on-orbit assembly of several ISOBUS Modules into complex spacecraft configurations.

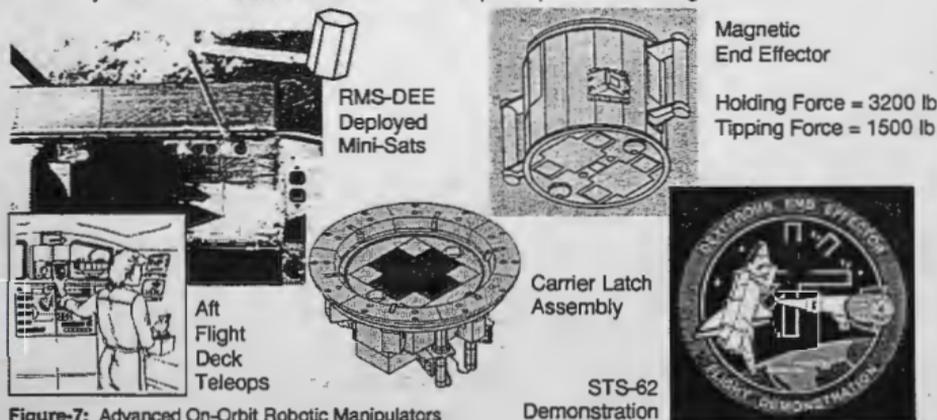


Figure-7: Advanced On-Orbit Robotic Manipulators and End-Effectors

ISOBUS SYSTEM DESCRIPTION

The ISOBUS system is multifaceted. However, it can be broken down into two distinct classifications, "non-deployable" and "deployable." **Non-deployable** ISOBUS Modules serve Shuttle cargo bay based investigations which remain in GAS canisters throughout the mission's duration. On the other hand, **deployable** ISOBUS Modules serve investigations which need to be removed from the GAS canisters on-orbit, such as: experiments requiring special attitude or exposure to the space environment while supported by the RMS, free flying experiments (e.g., mini-sats, micro-spacecraft), and EXPRESS experiments requiring attachment to Space Station. Both non-deployable and deployable ISOBUS Modules are

Figure-8: ISOBUS Module Installed in GAS Canister

designed to fit in GAS canisters (see Figure-8), which currently are the most commonly used Shuttle cargo-bay small payload carriers. However, ISOBUS Modules are designed for compatibility with other upcoming carriers, such as the Space Station Dry Logistics Carrier and the Station's on-orbit exposed facility, which will be attached to the Japanese Experiment Module (JEM). In addition, ISOBUS Modules could be arranged for launch on an expendable launch vehicle (ELV) such as Pegasus, Taurus, or Delta. The ISOBUS system involves the ISOBUS Module's primary structure, interfaces, and utility subsystems.

ISOBUS Module Structure

The ISOBUS Module's structure employs an Isogrid design. Isogrid consists of Computer Numerically Controlled (CNC) milling of a series of equilateral triangles out of solid plate stock (see Figure-9) to produce a structure which is six times as strong as a solid plate of equal weight. Isogrid structures made of aluminum are very competitive with composites in strength-to-weight-ratio. Aluminum Isogrid structures are also simple to manufacture and lend themselves well to structural / stress analysis. Isogrid has been successfully applied for the past thirty years in the aerospace industry (e.g., Delta Rocket, Skylab). The ISOBUS Module's primary structure is in effect an Isogrid rack (based on USU/SDL's ISOSAT design) consisting of six wall-panels, a top, a bottom, and intermediate shelves (see Figure-10). The outer wall-panels may or may not (depending on user requirements) employ a skin. The Isogrid lattice work provides tapped mounting holes at each lattice intersection node. This type of primary structure lends itself effectively to modular subsystems and varying user investigations and configurations.

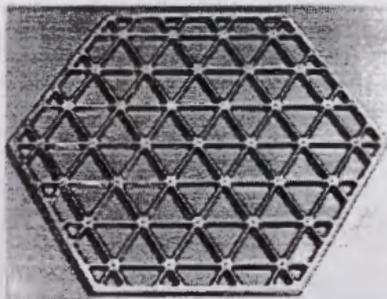


Figure-9: ISOSAT Isogrid Shelf

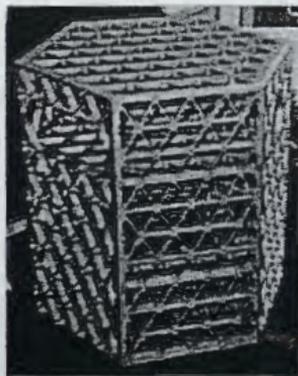


Figure-10: ISOSAT Isogrid Structure

ISOBUS Module Interfaces

The ISOBUS Module and its respective carrier (e.g., GAS canister) employ standardized mechanical, electrical, and fluid interfaces. These interfaces have quick-connect / disconnect and blind-mate / de-mate characteristics which allow an ISOBUS Module to be inserted into a GAS canister like an LRU/ORU (like a drawer into a cabinet). The mechanical interfaces involve insertion-retraction guide rails with spring loaded guide rolls and retention-locking mechanisms. These mechanical interfaces provide alignment of the electrical and fluid blind-mate / de-mate interfaces (connectors) during ground and on-orbit installation and removal. The mechanical interfaces also ensure that the ISOBUS Module is appropriately restrained through the various flight phases (e.g., launch, landing). The electrical interfaces

enable exchange of power, electronic data, and control with the Orbiter, Space Station, or with other interconnected ISOBUS Modules. Fluid connectors may also be used for circulation of radiator coolant, or transfer of consumables. Should on-orbit deployment and manipulation of the ISOBUS Module by the RMS-DEE be required, a DEE interface plate would be added to the top of the module. The DEE interface may also be used by specialized ground support equipment for module installations (and removals) into GAS canisters at the Shuttle Launch Pad and the Orbiter Processing Facilities. The DEE interface consists of a 12 inch diameter plate made of Permadiure (a ferrous alloy). The plate can range from 0.5 to 1 inch in thickness, depending on the required grappling force. Certain applications (e.g., Space Station attachment or a spacecraft configuration) may require ISOBUS Modules to be assembled on-orbit into various ISOBUS Cluster configurations. Special inter-compatible connector design will allow ISOBUS Modules not only electrical and fluid interconnection, but also physical interconnection top-to-bottom, and side-to-side (see Figure-11).

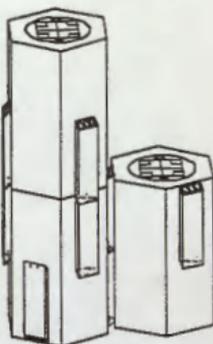


Figure-11: ISOBUS Modules Physically Interconnected

ISOBUS Utility Subsystems

ISOBUS utility subsystems are modular in nature allowing employment of the latest state-of-the-art technologies. ISOBUS subsystems are addressed in respect to each of the two distinct ISOBUS classifications of "non-deployable" and "deployable" configurations.

The basic ISOBUS utility subsystems for non-deployable applications include support structure, power, control, and data recording. The Isogrid-based support structure subsystem, including mechanical interfaces, has already been described above. The power subsystem may consist of a rechargeable battery package, power inverters / converters, and a set of power distribution relays. The non-deployable ISOBUS power subsystem is capable of tapping Shuttle power, if required, to run the investigation or perhaps recharge a battery package. The control subsystem is a modular computer which enables programmable or real-time (uplink or from Aft Flight Deck) control of the investigation as well as comprehensive data acquisition, processing, storage and/or relay back to the Aft Flight Deck and/or downlink. The computer is programmable via an IBM PC or a compatible. It employs libraries for easy software development. The computer's modular design offers various instrumented cards for measurement of background parameters, such as accelerations and temperatures associated with the investigation. The data recording subsystem is available as a part of the computer described above (e.g., with hard drive or optical disk storage). However, other data recording devices, such as video, can also be supported via the computer. Each of the ISOBUS subsystems is modular and can either be arranged with the investigation's unique instrumentation in a single ISOBUS Module, or be distributed in two or more modules which are interconnected for power, command, and data. Fluids subsystems for cooling or consumable delivery and other unique subsystems may also be arranged.

For ISOBUS deployable configurations, especially assembled spacecraft clusters, physical separation of subsystems into distinct modules can result in various standardized, off-the-shelf, certified, and catalogued building-blocks including power, navigation & attitude control, propulsion, command & control, communication, and so on (see Figure-12). For ISOBUS spacecraft, especially single-module mini-sats, miniaturized subsystems are key.

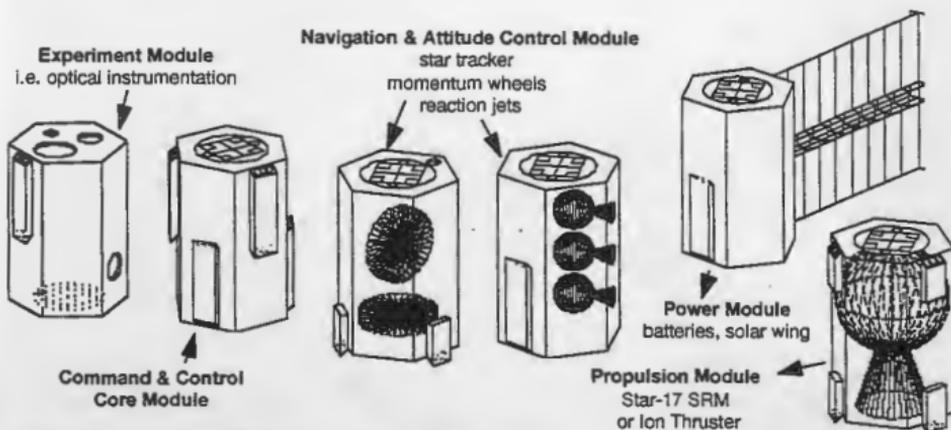


Figure-12: Deployable ISOBUS Module Building-Blocks

For deployed Space Station attached ISOBUS payload configurations the subsystems are similar, if not the same, as those available for non-deployed configurations, allowing for inter-compatibility between Shuttle- and Station-based investigations.

ISOBUS CONFIGURATIONS

The ISOBUS concept, as defined earlier, is based upon modular building blocks. The building blocks (ISOBUS Modules) are uniform in shape, size, and interfaces. These building blocks can be interconnected into various "non-deployable" and "deployable" configurations.



Figure-13: GAS Cans Mounted to Cargo Bay Sidewall

Non-deployable ISOBUS configurations may use one or more GAS canisters for housing the individual ISOBUS Modules, either mounted to the Shuttle cargo bay sidewall (see Figure-13) or to a cross-bay bridge carrier. For example, a pair of ISOBUS Modules in side-by-side GAS canisters can be interconnected for power, control, and data transfer (and also for fluid transfer) via the bottom or top of the two adjacent ISOBUS Modules. One GAS canister houses an Experiment ISOBUS Module, while the other canister houses a Utilities ISOBUS Module. The Utilities ISOBUS Module consists of several modular subsystems including power, command & control, and data recording. The Utilities ISOBUS Module is also electrically connected to the Shuttle Aft Flight Deck via a blind-mate / de-mate interface between the ISOBUS Module and the GAS canister's

Interface Equipment Plate. This "2-Can" ISOBUS configuration (see Figure-14) allows for more extensive utilities (e.g., power) and more extensive experiment volume. Even though interconnected GAS canisters have been flown, the packages within the canisters were not of a modular LRU nature which can be easily slipped into pre-mounted canisters late at the launch pad, as proposed with ISOBUS.

Deployable ISOBUS configurations, again, may use one or more GAS canisters to house respective ISOBUS Modules. Once on orbit, these modules are removed from the canisters using the Shuttle's RMS-DEE and either deployed as single mini-sats, or attached to Station as EXPRESS payloads, or interconnected into various spacecraft assembly configurations (see Figure-15).

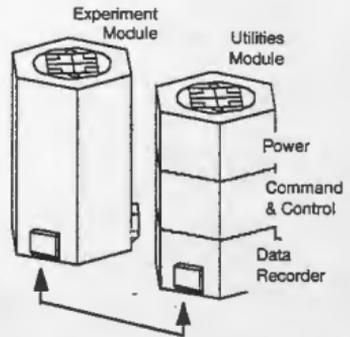


Figure-14: Non-Deployable "2-Can" Configuration

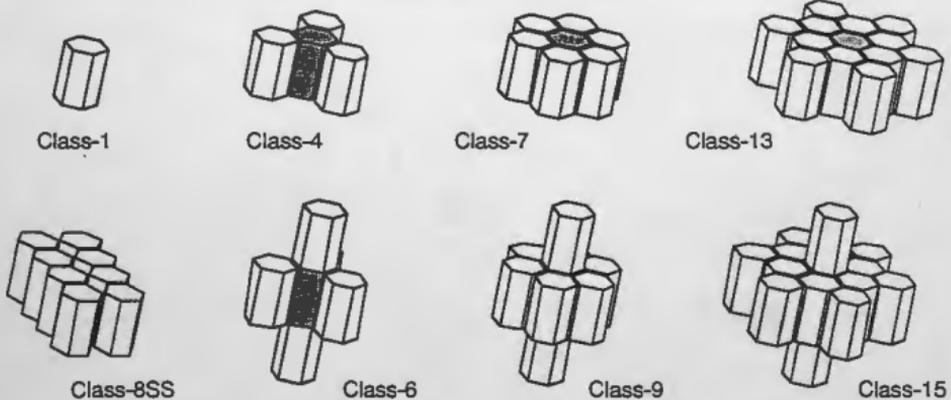


Figure-15: Deployable ISOBUS Configurations

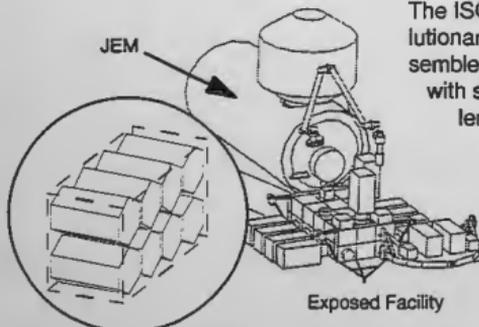


Figure-16: Deployable "Eight-Pack" Configuration for Space Station EXPRESS Attached Payloads

The ISOBUS Cluster approach allows for very revolutionary modular payloads or spacecraft to be assembled on-orbit from uniformly shaped building blocks with standardized interfaces (like "Space Lego"®), lending themselves to automated or robotic on-orbit assembly. In the case of Space Station EXPRESS attached payloads (see Figure-16), an "Eight-Pack" cluster configuration of eight ISOBUS Modules results in an assembly with overall dimensions (dashed line) fitting the allotted room for a payload attached to the JEM exposed facility.

In the case of Spacecraft assembly configurations (see Figure-17), ISOBUS offers a large variety of cluster configurations made from off-the-shelf subsystem modules and promising much "faster-better-cheaper" spacecraft development and deployment. ISOBUS spacecraft

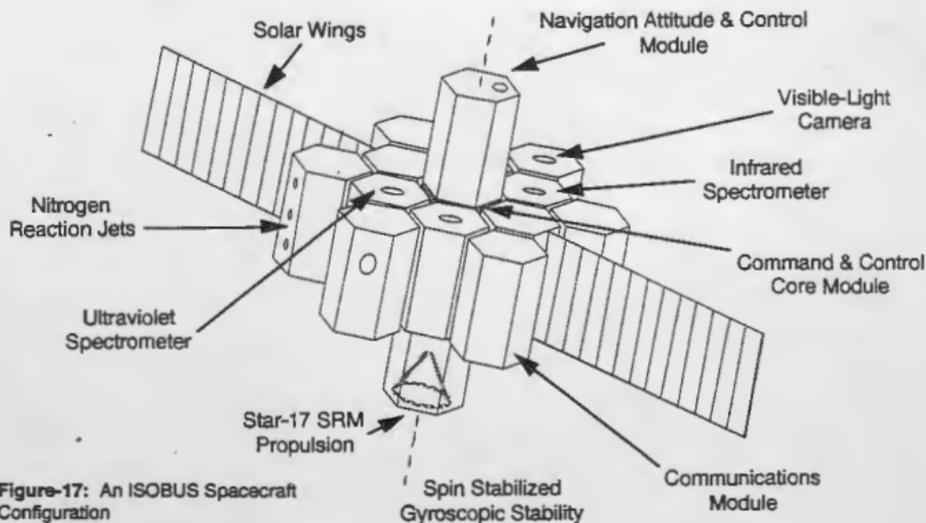


Figure-17: An ISOBUS Spacecraft Configuration

configurations may also provide for staged propulsion modules (see Figure-18) supporting near-Earth and interplanetary missions. Moreover, upon arrival at the mission's destination (e.g., a cometary tail or a planet) an ISOBUS Cluster spacecraft could separate into a network of individual science probes (each being an individual ISOBUS Module).

ISOBUS ADVANTAGES

ISOBUS can provide a versatile platform for diverse space investigators and sophisticated missions involving LEO experimentation, Earth observation, near Earth exploration, and even interplanetary exploration. ISOBUS should be advantageous because it provides a "faster-better-cheaper" approach.

ISOBUS should be **faster** because it reduces development time and simplifies integration and launch processing, through employment of standardized off-the-shelf subsystems and high-level modularity. The principal investigators (PI)s only have to worry about the investigation's unique instrumentation and mechanisms. They do not have to waste time developing utilities. The PIs simply pick from a catalog those utilities which best suit their investigation's needs, and design the investigation for compatibility with the utilities specifications (e.g., power, voltage, data format). In addition, the PIs prepare their end of the package to interface with the utilities modular end, reducing integration time. Hence, ISOBUS's modularity eliminates the complexity of integrated inter-meshed subsystems. Inter-module integration will not occur until

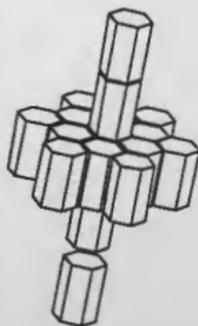


Figure-18: Staged Propulsion Modules

reaching the launch site or even until reaching orbit (depending on the ISOBUS configuration used). Interface Verification Tests (IVT)s, however, will be simulated at the PIs home location using a portable checkout unit prior to package delivery to the launch site and hard IVT's will also occur at the launch site prior to installation on the Shuttle. The standardized module interfaces will standardize and reduce required IVT's. Lastly, ISOBUS's LRU characteristics also enable late launch pad installation into pre-mounted GAS canisters, thus eliminating two to three months of payload processing.

ISOBUS should be **better** because it improves reliability and enables more science through employment of already proven and efficient utility subsystems, which leave more volume and resources for the investigation. ISOBUS utility subsystems will be highly reliable because they will be standardized, already certified, catalogued, and employed off-the-shelf. ISOBUS Modules will also be easily replaceable at the launch pad with spares in case of prelaunch anomalies or exhaustive launch delays. On-orbit replacement of an ISOBUS Module in order to correct a failed ISOBUS spacecraft subsystem will also be possible with ISOBUS's highly modular ORU-like nature. GAS ISOBUS mini-sat deployments using the RMS-DEE should be more controllable, thus safer and more reliable, than ejection. Eliminating ejection mechanisms also frees room for more science. The modularity of ISOBUS lends itself well to efficient usage by multiple PIs and to efficient utility subsystem management, resulting in increased room for science instrumentation via dedicated science modules. ISOBUS will facilitate the PI's access to space and increase the PI's chance of success.

Finally, ISOBUS should be **cheaper** because it employs standardization, reusability, simplification, and miniaturization. Standardization leads to efficient mass production, certification, and maintenance, resulting in cost savings. Off-the-shelf modular subsystems lead to excellence and price reduction through competitive commercialization. ISOBUS spacecraft will also enable mass-deployments of, consequently, more affordable investigations. Recoverable ISOBUS subsystems should be reusable making themselves even more affordable through leasing arrangements. ISOBUS's higher reliability means less failures and higher return on investment. On-orbit spacecraft integration would eliminate complex and expensive spacecraft structures and inter-meshed subsystems for launch. Separate modular subsystems are simpler to develop, repair, and maintain. The relatively small ISOBUS Modules simplify handling and launch processing. The ISOBUS Module drives miniaturization efforts to maximize its packaging efficiency. ISOBUS enables more cost effective deployment of mini-sats. ISOBUS's late pad installation capability opens more affordable opportunities for perishable specimen type-experiments, traditionally limited to the expensive Shuttle Mid Deck. ISOBUS's late pad installation capability also reduces program costs by enabling substitution of "lead ballast" with "smart ballast" space investigations.

CONCLUSION

Using our existing Space Shuttle Program and Shuttle Small Payloads infrastructure, ISOBUS introduces a new innovative approach to space investigations for GAS / Hitchhiker users, In-STEP, and Explorer-type programs. ISOBUS is also preparing for compatibility with the Space Station attached EXPRESS payloads infrastructure, striving to bridge Shuttle- and Station-based investigations. ISOBUS seeks to employ proven commercial methodologies such as standardization, mass production, miniaturization, modular interchangeability, and reusability of tools, facilities, and resources in order to achieve a "faster-better-cheaper" system for space investigators.