

**SpaceFrame: Modular Spacecraft Building Blocks
for Plug and Play Spacecraft**

Jon Miller

AeroAstro Inc.

20145 Ashbrook Pl.

Ashburn, VA 20147

(703) 723-9800 x135

jon.miller@aeroastro.com

Jim Guerrero

Air Force Research Laboratory

3550 Aberdeen Avenue SE

Kirtland AFB, NM 87117

(505) 846-5936

jim.guerrero@kirtland.af.mil

David Goldstein

AeroAstro, Inc.

327 A Street 5th Floor

(617) 451-8630 x11

david.goldstein@aeroastro.com

Tony Robinson

AeroAstro Inc.

20145 Ashbrook Pl.

Ashburn, VA 20147

(703) 723-9800 x133

tony.robinson@aeroastro.com

Abstract.

SpaceFrame is a highly capable, reconfigurable spacecraft architecture built around a modular set of mechanical “building blocks” called SpaceFrame Blocks (SFB). This paper will discuss the technologies and design approaches involved in the implementation of SpaceFrame-based spacecraft architecture. It will detail the characteristics of this method and outline the path forward toward on-orbit servicing and rapid reconfiguration.

Traditional satellite design approaches produce custom satellite buses with the exclusive goal of maximizing specific system performance. These satellites are composed of a selection of custom and semi-custom components that are integrated in a highly specific manner for that particular spacecraft. While this approach produces extremely efficient single spacecraft, it requires extensive, non-recurring engineering that results in large development costs and an inability to take advantage of development work from one system on the next system. The goal of SpaceFrame is to move away from expensive, proprietary system solutions with a single vehicle application towards less expensive, "modular" hardware solutions that support a variety of spacecraft applications.

The SpaceFrame technology involves mechanical and electrical ‘plug-and-play’ interfaces that permit simple, reliable integration with other SFB modules. The SpaceFrame technology is an important first step towards on-orbit configuration, servicing, and upgrading of satellites. The standardized mechanical and electrical interfaces allow one block to be easily removed and replaced with another. Ultimately, via autonomous rendezvous and docking, an existing space asset utilizing the SFB standard could be upgraded, augmented, or repaired through SFB addition or replacement.

AeroAstro is currently working with the Space Vehicles Directorate at the Air Force Research Lab, with commercial funding contributions from a third party investor (ATSB) to develop the SpaceFrame technologies and transition them into a commercial Small Payload Orbit Transfer vehicle (SPORT). SPORT is an upper stage vehicle designed to deliver a payload from GTO to LEO by means of a deployed aerobrake.

Introduction

Today's aerospace industry treats every space system as if it were a specialized project, each with a solution by definition completely different from any other. This focused custom approach produces beautifully designed and integrated systems at the cost of years of effort and millions of dollars. Even though most space systems have analogues that have been developed previously, aerospace companies are constantly redesigning systems to produce a product that fits their exact requirements. Costs, that for any other industry would be considered truly non-recurring, are incurred time and time again. Furthermore, the reliability of a custom system is relative to the money spent on its design. High reliability for a custom system requires a lot of time and money invested in each specific point of design.

In contrast, if every time someone wanted to purchase a personal computer they had to approach a computer designer with their exact requirements and allow them time to custom build a computer to specification, the price would increase significantly and schedules would be extended. As it is, a customer can walk into any computer store and walk out 5 minutes later with a complete system. Another 10 minutes at home is sufficient for setup and integration time. Because computer companies have anticipated their customer's recurring needs and built a product that satisfies or exceeds them all, only 15 minutes is needed to acquire a fully functional personal computer that fulfills all common requirements at a fraction of the cost of a custom built model. The interfaces are built in so that if a new or better technology becomes available, integration of the new components is quick and simple.

The SpaceFrame Solution

SpaceFrame is a reconfigurable spacecraft architecture using standard structural modules

and interfaces designed to be used as the basis for a commercial or production system rather than custom satellites. When used, it significantly decreases the effort and engineering needed for interface definition and design, shortens the integration and testing time, and makes space programs more affordable.

A primary feature of SpaceFrame modularity is the grouping of related subsystems into standardized structural modules in a way that makes them easily integrated to each other. These modules, or SpaceFrame Blocks (SFB), are then assembled as needed through the use of standard mechanical and electrical interfaces to become a fully integrated and operational satellite. Because the blocks are all connected through standard interfaces, they can be changed or upgraded throughout the lifetime of the satellite.

Technologies Involved

Standard Interfaces

The core concept behind SpaceFrame technology is the development of standard mechanical and electrical interfaces.

A classic example of interface standardization applied to the aerospace industry is the set of interface standards imposed on spacecraft by launch vehicles. Launch vehicles provide a set of ICDs to the payloads that define the interfaces that a spacecraft is required to meet in order to be launched. The mechanical interface consists of a bolt pattern that is formed to accommodate a separation device. The electrical interface consists of an umbilical cord for pre-launch satellite care and the electrical connections needed to activate the separation system. The interfaces defined are independent of the payload to be launched. If a payload does not require the full service that these connections provide, they are still included but not utilized.

The technique of including excess capabilities in interface design is commonly used in the commercial arena. Products are equipped with the ability to accommodate more capabilities than what are necessarily needed. This is essential for any product that claims the capability to accommodate upgrades. In a small spacecraft, the limiting factors are generally cost and volume, rather than mass. Therefore, the SFB architecture will follow this technique by providing a standard set of interfaces, which are used or ignored depending on program requirements.

These standard interfaces refer to both internal and external connections, and the breakdown of electrical interfaces for an SFB can be compared to those of a personal computer. Personal computers contain both external interfaces for keyboards, monitors, etc and internal interfaces to accommodate processors, memory boards, and other cards. Externally, each SFB will be equipped with standard mechanical and electrical connections that permit simple, reliable integration with other SFB modules and externally mounted components. Internally, an SFB will contain mounting locations for a variety of components, mostly VME-based. The electrical connectors and wiring harnesses will be made integral to the SpaceFrame block as possible. Internal flexibility must be allowed in an SFB to achieve the full range of modularity that is required for spacecraft development. Internal electronics will be allowed to vary as long as the standard interfaces remain intact.

There are two main SFB modules: the Core SFB and the payload SFB.

Core SFB

The Core SFB, when populated with avionics and other critical components, constitutes the nucleus of an SFB-based spacecraft. It

contains all the avionics and electronics necessary to support the spacecraft and its payload throughout the mission. These components can include, but are not limited to:

- Flight computer
- Batteries and related electronics
- Torque coils or rods
- Momentum wheels
- Radio transmitter and receiver
- Limited propulsion capabilities
- Star tracker
- GPS
- Other Attitude Determination Sensors

These systems are integrated into a structural module that is equipped with the standard SpaceFrame interfaces. The components incorporated in the Core SFB are selected specifically for the mission at hand and are placed at suggested locations within the module. The structure is equipped with the standard mechanical interfaces that attach it to the other SFBs and, if needed, the launch vehicle. Figures 1 and 2 depict two possible layouts for a Core SFB.

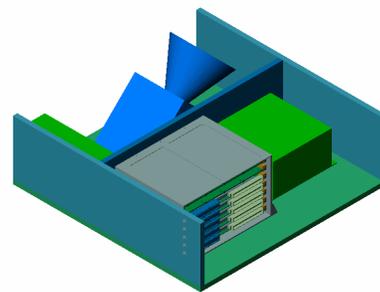


Figure 1: Core SFB

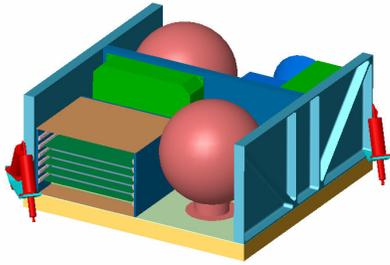


Figure 2: Core SFB with Propulsion Capabilities

All communication between the Core SFB components and the outside is conducted through the standard set of connectors and, wherever possible, through the integrated data lines in the SFB,

Payload SFB

The Payload SFB module, which is optional for use with the Core SFB, consists of a generic structure that is designed to accommodate most payloads or scientific instruments. Like the Core SFB, the components and internal layout of the Payload SFB can be optimized for program needs. The external interfaces will conform to the SpaceFrame standard. These standard external interfaces provide for the Payload SFB to be designed, built, and tested before being exposed to the Core SFB. The full sized Micro Payload SFB (Figure 3) is approximately 56cm x 56 cm x 65 cm. A half sized Micro Payload SFB has a volume of 56 cm x 56 cm x 30 cm (Figure 4).



Figure 3: Full Sized Micro Payload SFB

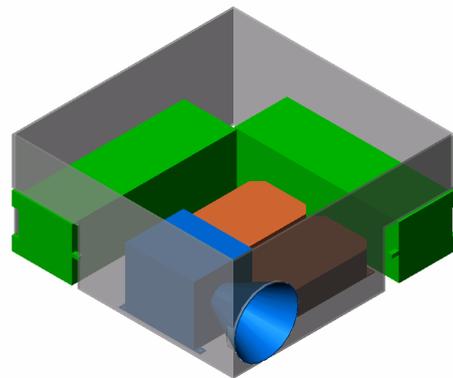


Figure 4: Half Sized Micro Payload SFB

The Core SFB and the Payload SFB contain all the basics needed by a satellite. Together they are the body of a SpaceFrame base spacecraft. Peripheral SFBs are incorporated to increase capabilities and address specific mission requirements. These SFBs tend to be units unto themselves; that is to say, they can be integrated with the other SFBs through the same SpaceFrame standard interfaces but their internal components are not as easily manipulated as are the Core and Payload SFBs.

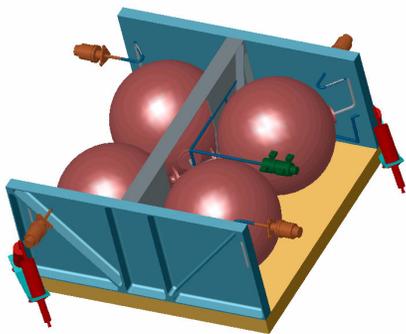


Figure 5: Propulsion SFB

Propulsion SFB

A Propulsion SFB (Figure 5) is used when a mission requires more propulsive capabilities than what the Core SFB can provide. It consists of a structure containing a complete propulsion system. The propulsion module will contain all the valves, thrusters, filters, etc that are needed for a propulsion system and the power and control lines will connect with a standard external connector. The Propulsion SFB can be attached to either the Core or Payload SFB. Propulsion SFBs are designed once and used repeatedly; offloading the tanks if less delta V is required. Essentially, a Propulsion SFB is a version of an upper stage on a launch vehicle. A micro-sized hydrazine propulsion module can contain four 23 cm diameter tanks and can carry up to 20 kg of propellant. Other propulsion technologies can be incorporated into a Propulsion SFB as need.

Aerobrake SFB

An Aerobrake SFB (Figure 7) is a generic deployable structure that, when deployed, provides a large effective surface area (30 - 150 m²) for aerobraking missions such as AeroAstro's SPORT (Small Payload Orbit Transfer) vehicle. The volume used for a stowed micro-sized aerobrake (approximately 30 m² deployed) consists of a 3-inch thick perimeter volume surrounding the spacecraft. (Figure 6) The Aerobrake SFB uses the same standard mechanical and electrical interfaces

to connect to the other SFBs. The primary use for this structure is to provide sufficient profile area to accomplish aerobraking when the satellite dips into the atmosphere, in order to reduce the orbit altitude by way of atmospheric drag.

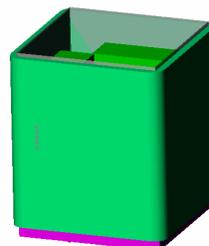


Figure 6: Aerobrake SFB Stowed

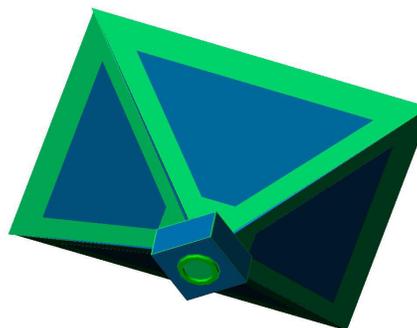


Figure 7: Deployed Aerobrake SFB

Deployable Array SFB

Another variety of SFB provides rigid deployable solar arrays. (Figure 8) It connects with the rest of the satellite by means of standard hinges and mounting points and provides power through a standard electrical connector. Each SFB consists of one deployable panel with standard interfaces and can be incorporated at any location or orientation desired.

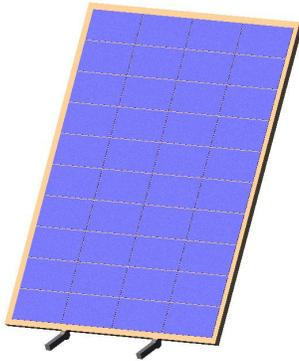


Figure 8: Deployable Array SFB

Any additional function or capability that is needed can be placed within a standard structure and equipped with the standard SpaceFrame interfaces. These added SFBs can be integrated into a new spacecraft or used to upgrade an existing system.

Designing a Satellite Using SpaceFrame Technology

The method of using SFBs to develop a satellite is best explained through the use of a simple example. AeroAstro is currently developing the Small Payload Orbit Transfer vehicle technology demonstration (SPORT-TD) with the use of SpaceFrame technology. Its mission is to deliver a payload from GTO to LEO by way of aerobraking while demonstrating the technology used. The mission will include various sensors, auxiliary payloads, and a small deployable module. SPORT-TD will need extra propellant for demonstration purposes. A simplified version of the design process is outlined below.

Phase 1: Requirements Definition and SFB Selection

The first step to any program is requirements definition. The mission requirements should correlate directly with the type of SFB selected. The primary requirements for the SPORT-TD mission are:

1. SPORT-TD shall contain all electronics necessary to complete the mission and control the satellite on orbit. Details of this requirement define what will go into the Core SFB.
2. SPORT-TD shall carry various payloads in the form of sensors and auxiliary payloads, as well as a small, deployable payload. Details of this requirement define what will go into the Payload SFB.
3. SPORT-TD shall have the propulsion capability to carry out the requirements of the mission. This propulsion capability is greater than what can be provided in the core module so a propulsion module will be needed.
4. SPORT-TD shall generate enough power on orbit to keep it alive. The power needed for the mission requires deployable panels.

Phase 2: SFB Selection and Design

Core SFB

The Core SFB will contain all the central electronics needed for the spacecraft. The SPORT-TD Core SFB will contain:

1. The flight computer that will control the spacecraft as well as send commands to the other SFBs
2. Communications
3. Complete Attitude Control system
4. Batteries and related electronics

This module is assembled, integrated, and tested apart from the other SFBs. All communication between the Core SFB and the other SFBs are channeled through the standard electrical connectors positioned on the mating surfaces.

Payload SFB

The Payload SFB for the SPORT-TD contains a small payload to deploy into LEO, a dosimeter, and a set of auxiliary payloads. These are integrated into a single structure with all communication to the components of

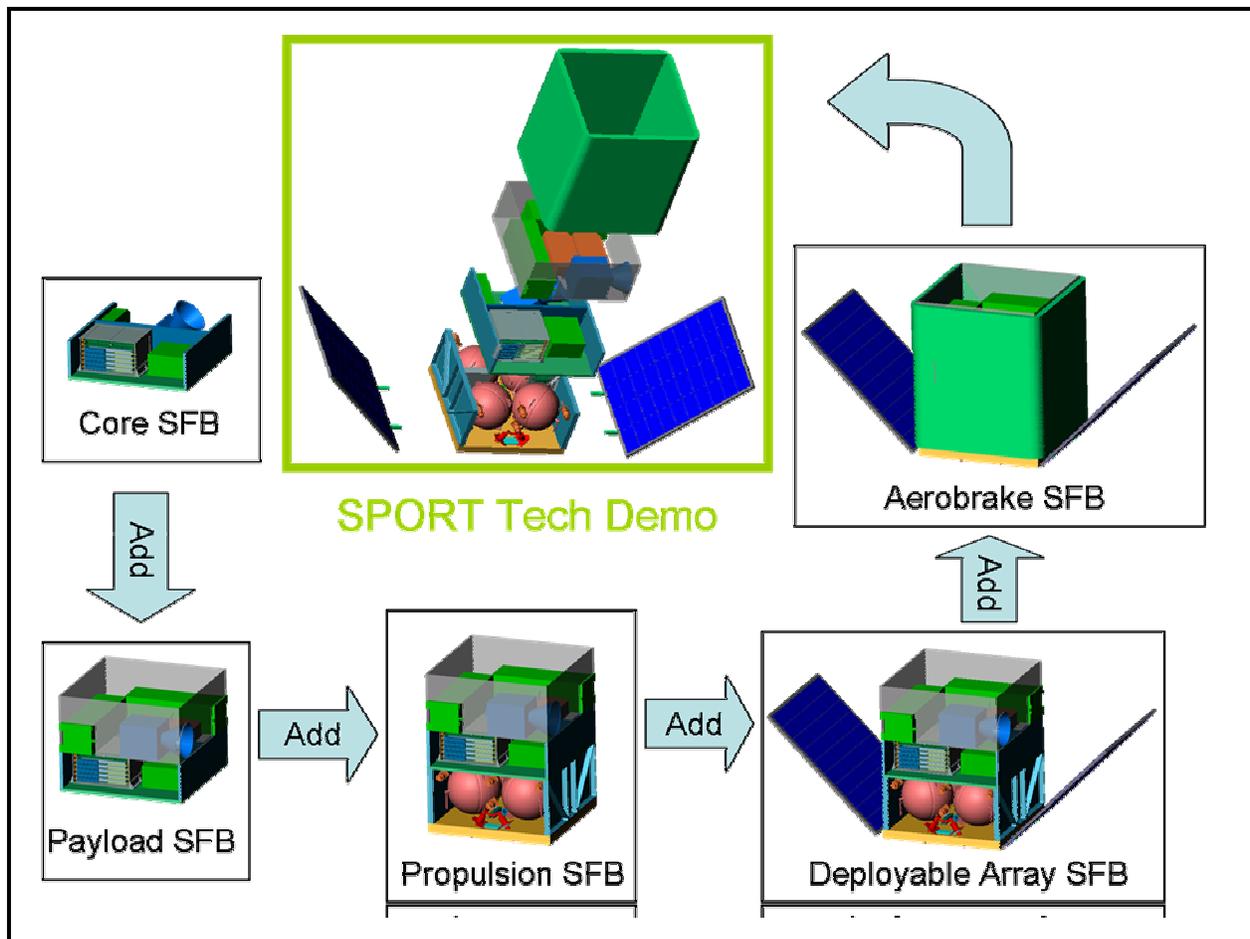


Figure 9: SFB Selection and Design Process

the Core SFB conducted through the standard interface. The Payload SFB can also be designed, integrated, and tested prior to its attachment to the Core SFB. The use of the standard interfaces assures a smooth integration.

Propulsion SFB

As stated in the requirements, SPORT-TD will require more propulsive capabilities than can be provided in a Core SFB. This requires the use of a Propulsion SFB. The selected Propulsion SFB is contains a hydrazine propulsion system. This SFB is attached through standard interfaces to the Core SFB. All electronic parts are connected to the flight computer which will control all propulsive maneuvers.

Aerobrake SFB

The Aerobrake SFB is integrated next. Again, if the standard interfaces are used, this integration process will not have problems. The stowed aerobrake can be packaged and tested prior to being introduced to the spacecraft. This is the most custom SFB in the SPORT-TD development process.

Deployable Panel SFB

Deployable panels are added next. They are attached using standard hinge mounts in standard locations and the power generated is routed through standard paths to the Core SFB. SPORT-TD will require four panels, one for each side. Once the panels are stowed, the satellite is completely integrated.

Phase 3: Integration and Test

Each SFB is assembled and tested separately. When they are completed, they are brought

together and integrated into the final product. The existence of a standard bus architecture using SFB components enables each SFB to be designed, built, and tested separately and integrated only at the end of the project with confidence that everything will fit together and work properly. Because each component was tested individually beforehand, testing the assembled SPORT-TD will not be as rigorous or time consuming as testing a custom, completely untested system.

Phase 4: Review the Program

In this development program, AeroAstro will review which steps were minimized or eliminated from the standard satellite design process because SpaceFrame technology was used. Assessment areas include:

1. Can each SFB be designed, integrated, and tested independent of the others, reducing the effort needed in team coordination?
2. Is integration of the core electronics is simplified because each component has a recommended location and the interfaces are already designed?
3. Does reliability of the system increases because, not only are proven parts used but proven systems as well?
4. Is there anything learned or developed that can be directly transmitted to the next program or added to the SFB library?

Path Forward to On-Orbit Servicing and Reconfiguration

Standard interfaces and assemblies lead the way toward upgrading and modifying satellites on-orbit, thus extending the usefulness of existing hardware and decreasing lifetime cost of the overall system.

Step 1: Standard, Re-configurable Modules

The path forward for SpaceFrame technology begins with the development of standard, re-configurable modules that can be manipulated and integrated here on the ground. Standard

interfaces that meet all foreseeable requirements must be defined. Every time a SFB is developed and used, the technology gained can be applied directly to the next SpaceFrame based program.

Step 2: Launch Site Integration

Launch-site integration of a payload and bus is the important next step in the SpaceFrame path forward. Launch-site integration refers to two SFBs which are designed and built in complete isolation and are only introduced to each other at the launch site. This will occur when interfaces are well enough defined that there is confidence that the two modules will mate successfully. The ability to accomplish launch-site integration can be a large advantage to those who wish to simplify their programs. For example, classified payloads could be mounted on a cheaper commercial bus without the risk of revealing classified material.

Step 3: On Orbit Integration, Upgrades, and Servicing

The SpaceFrame technology is an important first step towards on-orbit manipulation of spacecraft. The standardized mechanical and electrical interfaces, when combined with docking and servicing hardware, will eventually allow one SFB to be attached to another during autonomous operations. Spacecraft can be launched in parts instead of as a full vehicle. This provides another means to find the least expensive access to space. In the same manner, an existing space asset utilizing the SFB standard could be upgraded or repaired through SFB addition or replacement. A satellite that is nearing the end of its scheduled lifetime could be provided with the assets to continue its mission or to perform a new one. Propulsion modules could be launched to provide additional boost to a faltering spacecraft. Missions that would otherwise be lost could be reclaimed through the addition of a new

power source, the replacement of a non-functioning communications system, or the replacement of a sensor or other faulty component.

Conclusion

SpaceFrame is a modular spacecraft structure complete with standard internal and inter-modular interfaces. SpaceFrame technology refers to the grouping of related subsystems into modules in order to simplify the design and integration process and reduce costs and development time. SpaceFrame blocks can be designed, built, and tested separately and then integrated only at the end of the program. SpaceFrame is the first step toward on-orbit servicing and integration of spacecraft.