In-Situ Technology Test Bed (ISTTB)

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ABSTRACT

The In-Situ Technology Test Bed (ISTTB) is a new, technology demonstration platform for electronics, software and hardware. The ISTTB contains several standard interface slots that carry the Devices-Under-Test (DUTs) and an all-purpose flight computer to test software. The ISTTB platform will: measure the radiation experienced by the payloads; read the spacecraft sensors; capture payload data; and send the telemetry to a ground station.

The ISTTB fulfills all the definitions of a small satellite: orbiting spacecraft with low power and low mass, however, the ISTTB will be permanently attached to a Rideshare adapter. The ISTTB is a reusable 'spacecraft bus' design that demonstrates new technology in a real-world radiation environment, integrates with real-world hardware for 'in-the-field' experimentation and system performance characterization, and yields a competitive-edge for all its payloads by increasing Technology Readiness Levels (TRLs) at an inexpensive 'firm-fixed' price.

The ISTTB solution offers several advantages over other technology demonstration programs such as the New Millennium Program and TacSat such as: offers 100% dedicated on-orbit testing time; multiple launch opportunities; and 'primary payload' designation. The ISTTB is a new, highly useful 'market' for the small satellite community. First deployment of an ISTTB platform is scheduled for the 2008-2009 timeframe.

MISSION

"Inadequate funding, fear of failure, red tape and high launch costs conspire to make it difficult to take promising new technologies from the laboratory to orbit."¹ Subsequently, it is commonly accepted throughout the aerospace industry that only "proven flight technologies" are the ones that repeatedly get selected for government, civil and commercial missions. The challenge of all aerospace companies trying to develop new technologies is to convince a mission manager to initially accept the risk of their new product. Without 'flight heritage' and some testing in a 'real-world environment', even the most efficient products for the job have to pass several 'psychological hurdles' in order to get manifested. This roadblock in the technology development process limits the science and the tactical usefulness of many missions.

The In-Situ Technology Test Bed (ISTTB) addresses this dilemma. Redefine Technologies Inc (RTI), Space Access Technologies (SAT) and the Colorado Space Grant Consortium (COSGC) are working together to build and launch the first ISTTB mission. The ISTTB enables board manufacturers, software programmers and hardware designers to immediately take their technology from the laboratory to orbit. The ISTTB is a new, technology demonstration platform dedicated to advancing new aerospace technologies. The ISTTB is a reusable 'spacecraft bus' whose payload is a suite of devices to be tested in space.

The mission is simple: to provide an in-situ technology demonstration platform. The requirements for such a mission include:

- Provide an orbiting 'real-world testing environment';
- Support electronic boards with a standardized physical and data interface;
- Supporting software packages on a dedicated processor with the appropriate interfaces simulated;
- Support a variety of hardware attachment points and various interfaces to actuate the hardware;
- Measure the environment of the test (i.e. the radiation experienced by the payload, temperatures, voltages, attitude, etc.);
- Capture data from the device under test (DUT) (whether that data be from hardware, an electronics board or from software running on the test processor); and,
- Send the telemetry to a ground station.

There are two variants of the ISTTB: the Electronics ISTTB and the Hardware ISTTB. The Electronics ISTTB payload accommodates three customer-provided electronics boards and enough processing capability to support those boards. The Hardware ISTTB has an open-bay area capable of holding several hardware payloads in the volume prescribed. Both the Electronics and Hardware ISTTB are also able to demonstrate individual standalone software packages provided by the programming community.

Technically speaking, the ISTTB fulfills all the definitions of a small satellite: orbiting spacecraft with low power and low mass. The ISTTB has a command and telemetry system, a power system, an attitude determination system, and a thermal system. The main difference, however, is that this small satellite will be permanently attached to the Rideshare adapter (shown in Figure 1) offered by SAT.



Figure 1: Rideshare Adapter

Rideshare is an adapter ring specifically designed for several launch vehicles. The Rideshare Adapter (RSA) is the interface between the launch vehicle and a large primary payload (shown in Figure 2). Attachment points for a variety of equipment exist on the adapter itself. The ISTTB will be a reusable 'spacecraft bus' design mounted to the sides of the RSA.



Figure 2: Rideshare Adapter between the primary payload and the launch vehicle.

SPACECRAFT BUS

Each ISTTB are separated into two individual structures and mounted on opposite sides of the RSA as shown in Figure 3 and connected via a wiring harness. The two structures are called the Payload Box and the Battery Box. The components each flight box contains are listed in Table 1.



Figure 3: Rideshare Adapter With The Two ISTTB Structures Attached on Opposite Sides

A cut-away model of the Payload Box is shown in Figure 4 and the Battery Box is shown in Figure 5.

Table 1:	Components	of	ISTTB
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Box	Components	
Payload Box	Primary Flight Computer	
	Communication System	
	 Payload (includes slots for electronics boards, a bay for hardware and a separate processor for software) 	
	Support Boards	
	• GPS receiver #1	
	• Solar panel #1	
Battery Box	• Battery	
	• GPS receiver #2	
	• Solar panel #2	





b) Hardware ISTTB

Figure 4: Payload Box Cut-Away Model for Two ISTTB Variants





In the case of the Electronics ISTTB, each of the red payload DUT boards shown in Figure 4 are placed to maximize their radiation exposure during flight. Typical electronics testing in space will desire the greatest exposure to best characterize their response to harmful environmental factors. The Flight Computer, the Comm System and the GPS Receiver are given the greatest shielding in this configuration. In the case of a Hardware ISTTB, the payload bay will resemble a true flight situation as closely as possible.

The Flight Computer will likely be a veteran single board computer such as Space Micro Inc.'s Proton100K. This computer already has a proven flight history and a well-characterized radiation response. The Flight Computer will interface with: all the DUT payloads; the Comm System; the GPS receivers; and the Support Boards.

The Support Boards are present in both ISTTB variants. The main purpose of both versions is to support the payloads being flown. The Electronics Support Boards consists of two perpendicular boards. The Baseplate board is the main bus that allows each of the vertical boards to communicate to each other. The vertical Support Board bridges the main bus communication to the out-of-plane DUT. This vertical Support Board (in both the Hardware and Electronics variants) also houses the Electrical Power Subsystem and Payload Support electronics. This board will support the electrical power distribution throughout the Payload Box. This board will also provide support electronics for the software and other devices being tested. The Support Board is a custom-built board that includes electrical components that will:

- take power from the battery or directly from the local solar panel and provide that energy to the payload,
- include a processor dedicated to running customer software,

• supply test data and test connections to the DUTs for real-hardware testing and data rates.

The Battery Stack contains multiple Ni-Cd cells specifically sized to provide full-orbit, continuous power for the ISTTB. There will be simple charging circuitry collocated with the Battery Stack that will properly maintain the best charging environment using the two sets of solar panels. This charging circuit will also have components that can help maintain an optimal thermal environment for the battery stack.

The Communication System is an S-band transmitter and receiver. Downlink speeds are 8Mbps and uplink can occur at 1kbps. These speeds may possibly change and the STTR website (<u>http://www.isttb.com</u>) would have up-to-date information.

The GPS Receivers are included in both the Payload Box and the Battery Box to provide attitude and position determination. Having two receivers separated by the diameter of the RSA (which varies corresponding to the launch vehicle it was launched on), allows for an accurate knowledge of attitude to within a few degrees over a series of observations. The RSA does not have any active attitude control for the ring itself; therefore, the GPS receivers are all that are needed to give an accurate picture of the flight path of the DUTs.

Solar panels for both boxes are mounted on the tops of the boxes. These panels will charge the battery stack when facing the sun. Since there is no attitude control, these panels have to be sized large enough given that only one can be facing the sun at any given time. Having one panel on either side of the RSA offers the greatest charging capability from the most angles throughout the uncontrolled flight. Alternate designs are being analyzed to determine the feasibility of greater solar panel areas as illustrated in Figure 6.



Figure 6: Solar Panel Placement Options.

PAYLOAD SUPPORT

Currently, the Electronics ISTTB can launch three electronic DUTs of various interface standards. The first two slots are 3U Compact PCI and the connector on the third slot can vary per mission with a new Support Board. Other connectors that could be used include a PCI-Express, SpaceWire, RapidIO, etc. Designs are in development to support 6U form factors and other interconnect standards. Each DUT must conform to the requirements found in Table 2. A more accurate and up-to-date requirements document can found the also be on ISTTB website (http://www.isttb.com).

	Requirement	
Size	x: TBD	
	y: 241mm (9.5")	
	z: 133mm (5.25")	
	Interface: cPCI, PCIe, SpW, RapidIO	
Mass	0.5 kg (1.1 lbs)	
Power	input voltage: 5V	
	max current: 2A	
Thermal	-5 C to +20 C	
Vibrational	19grms	
Other	Space-rated components, soldering, etc.	

 Table 2:
 Electronics DUT Requirements

The Hardware ISTTB variant has approximately 4000 cm^3 (261 in³) of volume and 2.0 kg (4.4 lbs) of mass. The hardware DUT payload can be housed inside the Payload Box or it can be exposed to space. Standardized mounting holes are identified in the ISTTB Interface Control Document (ICD) for hardware manufacturers to design towards. Figure 7 shows some possible configurations to test deployable structures, actuating devices, material properties or other technologies.

Mission operations support is included in the ISTTB cost per customer. This support takes advantage of the fact that all DUT and software 'payload' data are communicated to the ground simultaneously. While the telemetry rate varies depending on the mission that the ISTTB is riding with, each hardware and software customer will be encouraged to keep their telemetry short and summarized to get the highest resolution for their high-speed analyses while on-orbit.



a) fold-open flaps to expose new materials or solar panels



b) open payload area to expose instrument



c) dedicated payload box where Flight Computer would be housed in Battery Box

Figure 7: ISTTB Configuration Options for Hardware.

THE ISTTB CONCEPT

The ISTTB offers new technology developers:

- an increased number of flight opportunities,
- a much lower cost ride into space,
- a real-world testing environment,
- "primary payload" status and 100% testing time,
- the chance to increase their product's Technology Readiness Level (TRL) and gain flight heritage, and
- an opportunity to advance the industry 'in front' of Moore's law.

Increased number of flight opportunities

The concept behind a technology testbed is not new. In the 1999-2001 timeframe, NASA proposed a similar, but more limiting program called the Orbiting Technology Testbed Initiative (OTTI). OTTI was to launch only a few testbeds into high-radiation orbits to simply *assess the interest* by NASA enterprises, other government agencies, and industry partners. Unfortunately, in 2001, NASA canceled the OTTI. Today, the ISTTB is in an even better position to follow the OTTI study because of the 'recurring' launch opportunities on many of the future launch contracts.

Also at its inception in 2000, the Living With a Star (LWS) Program was to also undertake a similar target audience where a variety of technologies could be tested on their Space Environment Testbed (SET). Unfortunately, the LWS Program has moved to a more space weather-focused program. Unless new technologies specifically address the Sun/Earth interactions, they cannot be flown on SET. The ISTTB has been specifically left open to any and all technologies to fly their projects because new ideas are needed for all aspects of military, civil and commercial missions.

In current times, several attempts from various institutions have been made to address the problem of getting promising new technologies from the laboratory to orbit. For instance:

- NASA offers their New Millennium Program (NMP) missions whose primary purpose is to "validate new technologies to reduce their cost and risk".
- The Defense Advanced Research Projects Agency (DARPA) and other commercial institutions try to adapt a "cultural shift" within their organizations that is more 'accepting' of new technology.
- The Air Force Research Labs (AFRL) offers their Tactical Satellite (TacSat) program designed to demonstration low-cost, quickreaction space capabilities.

While all of these approaches help to fund a handful of new technologies to get into orbit, there are a countless number of other promising startup products and ideas that may never see the real vacuum of a space because there are not enough 'test slots' available on any given series of technology demonstration programs. Even the big push to reduce launch costs themselves through DARPA's Falcon program would leave a relatively large price tag and the 'justification hurdles' would remain for new technologies to overcome in order to fly.

The recurring launch opportunities of the ISTTB substantially increase the number of 'slots' available that electronics, software and hardware manufacturer's have to put their products into orbit. It is anticipated that at least one or two launches per year are feasible. Because each launch can contain multiple DUTs, ISTTB alone can double (if not more) the number of electronics boards or experimental hardware put into space per year. Given that the majority of boards and hardware on other missions are ones with "flight heritage", and other programs like NMP and TacSat only launch one vehicle every few years, then ISTTB is the only option for today's fast moving technologies.

Lower cost ride into space

Having seen that there are very few opportunities to get a new product on-board one of the 'typical' missions, a company may want to investigate how much it would cost to 'pay for a ride' into space.

They could build their own satellite or fly on-board a satellite that is already being built. Given that typical missions cost on the order of 10's of millions to 100's of millions of dollars each when you include launch costs, the most novice of corporate executives would rule that option out immediately. One would then have to consider flying aboard someone else spacecraft as an alternative. However, given the delicate nature of all spacecraft with respect to power consumption, launch vibration analysis, the cost of mission operations while on-orbit, and all the testing and validation required at all stages of development, a company probably cannot even buy space on someone else's spacecraft bus. There would just be too much engineering overhead to justify the costs of that effort. A conservative estimate might allow for three full-time-equivalent employees (FTEs) to work a year on the issues for a single mission. Combined with another conservative estimate of \$200/hour, that would be over \$1M to test a board or a software package in space. In addition to the actual engineering costs, the company would still have the 'justification hurdle' to cross to convince the 'primary contractor' that the 'experimental payload' will not hurt or hinder the operations and data of the 'paying' customer's payload.

ISTTB is in a perfect position to leverage the benefits of the Rideshare Adapter. The RSA was specifically designed to use the excess launch capacity of any mission that is launched. When the primary payload does not use 100% of the mass that the launch vehicle can carry, the remaining mass can be distributed around the adapter. This helps the primary launch provider offset their costs of launch, but it also gives the ISTTB the advantage of bypassing many of the 'justification hurdles' of the 'experimental package' being on the same bus. Any uncertainties involved with the 'experimental package' simply riding up on the same vehicle are already being addressed by Space Access Technologies through vibration analysis and proper interfacing standards.

In addition to utilizing any excess launch capacity, the ISTTB distributes the cost per pound over several customers. Given that the Electronics ISTTB has three DUT slots and processing capability for extra software customers, and the Hardware ISTTB can carry multiple payloads from multiple customers, the approximately \$600K of launch costs get distributed over each project. This yields a low-cost access to space for new technology trying to make a mark in the industry.

Real-world testing environment

There is no other 'real-world environment' for testing spacecraft components like actually testing them in space (i.e. in-situ). Many ground-based environments simulate the space effects like radiation, temperature swings, and mechanical vibrations. However, they always seem to fall short of 'conclusively' assuring a manager that this entire battery of tests will ensure the component will operate correctly on orbit. Table 3 outlines some of the limitations of ground-based testing.

 Table 3:
 Limitations of Ground-Based Testing

Test Methodology	Limitations	
Cyclotron Beam	Expensive $(\$1000/hr^2)$.	
	Have to wait for opportunities and between opportunities.	
	Only specific species of radiation tested at one time.	
Thermal-Vacuum Chamber	Temperature variations are slow Expensive to maintain equipment or rent when needed.	
Mechanical Vibration and Shock	Vibrations are single plane, not three dimensional Expensive to maintain equipment or rent when needed.	

While the ISTTB will not eliminate the need for ground-based testing, it does add that extra 'confidence layer' on top of the testing already performed. This 'confidence layer' speaks to a mission manager much 'louder and clearer' than ground testing alone.

The first ISTTB flight will carry two electronic boards from two different companies (the third slot is still open at this time). Redefine Technologies Inc. will supply the first board as part of a Phase II STTR with NASA Ames investigating 100% mission reliability using new FPGA redundancy techniques. The second board will be the Proton300K from Space Micro Inc. Their board is a radiation hardened-by-design single board flight computer in production for military and space applications.

To Redefine Technologies, Space Micro and other electronics companies, the ISTTB is an alternative and complimentary option to cyclotron beam testing.

Primary payload status

Since the ISTTB is an actual spacecraft in-orbit on a dedicated spacecraft bus, the electronic DUTs, the software DUTs, and the hardware DUTs are all considered 'primary payloads'. Since the purpose of these payloads is to simply operate and run their own 'isolated' experiments, the payloads can have 100% of the testing time. Most DUTs will normally run independently and dump their telemetry to the flight computer for downloading. Depending on the software packages loaded, each one may have to run independently in order to fully test their capabilities on the single processor.

Even though each DUT and software package is powered independently and providing their own test results, both hardware and software need some external 'stimulus' to act upon. For example, hardware typically needs an input on their I/O pins in order to produce an output on the corresponding output pins. Similarly, software would typically react to sensors readings from an instrument and actuate a device in response.

Anticipating these 'requirements', the ISTTB offers simple sensors and instruments/actuators to test with. This sensor suite and instrumentation is not set and can vary each flight. The students at the Colorado Space Grant Consortium are tasked with identifying those devices that would best suit the ISTTB mission. These devices could be high-speed data providers or they could simulate any device desired. The simulation would be hosted on hardware with the appropriate interfaces. This integration with real-world hardware provides authentic 'in-the-field' experimentation and system performance characterization.

Increasing TRL and earning flight heritage

All ISTTB flight opportunities provide a significant competitive-edge (i.e. flight heritage) to the manufacturer upon successful (or even partially successful) operations. This flight heritage alone helps elevate a product to a level that may result in future selection for military, commercial or civil missions. For example, a third company will also be flying a new flight software package on the first ISTTB launch. This flight software package will receive sensor readings just as the primary flight software does. The on-orbit scheduling routines will respond to these sensor readings and those responses will be captured as telemetry for analysis. While this seems simple enough, this demonstration takes the software from a NASA rated TRL level of 6 to a 7 (or 8 in some cases).

Getting in-front of Moore's Law

Moore's law is the empirical observation that at our rate of technological development, the complexity of an integrated circuit with respect to minimum component cost will double in about 24 months.³ With today's technology testbed launch rate of approximate one every few years, it is obvious that many technology applications cannot even be fully tested before they become obsolete. The ISTTB provides slots for at least 12 - 24 burgeoning technology demonstrations within the same time period. Not since the Mercury, Gemini and Apollo days have so many new technologies been fielded to advance the catalog of space-rated components.

FUTURE OF ISTTB

The first flight of the ISTTB is scheduled for the 2008-2009 timeframe on a geo-transfer orbit (GTO). This flight will be an Electronic ISTTB payload that tests several electronic boards and software for various companies. Future flights of the ISTTB (Electronic and Hardware variants) are currently being manifested. Future flights will test flight mechanisms, instruments and concepts.

The opportunities that ISTTB provides for new technologies will help a myriad of industries.

- Operational Responsive Space (ORS) can quickly test new technology from a 'strictly technological' standpoint and leave the 'integration overhead' to their TacSat missions. (i.e. a two-pronged approach to responsiveness: proving technologies and proving operational concepts).
- NASA's Living with a Star program can continue to concentrate on their Sun-Earth connection and leave the 'flight details' to the ISTTB team.
- Commercial companies propose that all new technologies will be 'flight tested' prior to using on 'real-science' or 'real-tactical' missions. This gives government and military

leaders the 'confidence' to choose them for future multi-million dollar mission.

- Deep-space missions could validate new hardware before integrating onto a one-shot mission.
- Ultimately, all aerospace missions will have a larger pool of qualified components to choose from. This larger technology base leads to better science and more useful tactical outcomes.

² G. Swift, "Radiation Effects and FPGAs", 2006 Military and Aerospace Programming Logic Device Conference

¹ B. Iannotta, "'Crossing the Valley of Death' to Get New Technology Into Space", Space News, April 23, 2007

³ <u>http://en.wikipedia.org/wiki/Moores Law,</u> June 7, 2007