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Paper Session III-B - Risk Management for Small Satellite Programs

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Risk Management for Small Satellite Programs

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ABSTRACT

During an era of shrinking federal budgets, the Space Test Program has developed a management philosophy for accepting greater risks in managing small satellite programs for technology demonstration. This innovative philosophy complies with the latest government initiatives to reduce cost by using contractors' best practices, eliminating use of government specifications and standards, and minimizing the size of the program office. We achieve program cost goals by matching the contract type to the perceived program risk, reducing program documentation, using non-redundant subsystems where possible, relaxing test requirements, and using minimal staff during on-orbit operations. However, we mitigate these increased risks and successfully perform our mission by developing detailed payload requirements early in the program, building system redundancy in appropriate areas, and applying vigorous attention to the spacecraft interfaces to the payload, the launch vehicle, and the mission control center. While these practices may not be appropriate for all satellite programs, we feel they apply to a broad range of research and technology demonstration spacecraft.

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I. INTRODUCTION

Since 1966, the Space Test Program (STP) has carried out a Congressional mandate to provide spaceflight opportunities to the top-ranked Department of Defense (DoD) space experiments not authorized to fund their own flight. Annually, the DoD Space Experiment Review Board (DoD-SERB) reviews space experiments nominated by DoD organizations. The DoD-SERB then ranks the experiments based on military relevance (60% of score), service ranking (20%), and experiment quality (20%). STP attempts to fly as many highly ranked experiments as possible within existing budget constraints and flight opportunities. An outline of this process appears in Figure 1.

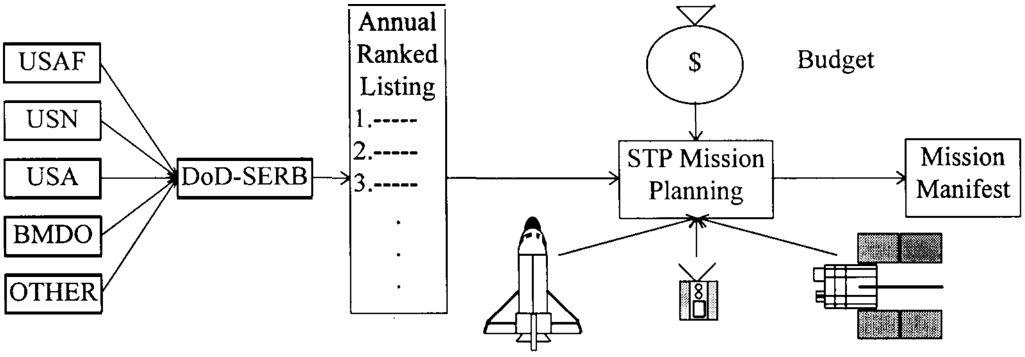

Figure 1: DoD-SERB Process Flow

STP specializes in providing access to space using the Space Shuttle, excess payload capability on other space vehicles (US, commercial, and international), and by building one-of-a-kind free-flying spacecraft to meet particular experiment requirements. The STP record boasts over 50 space missions flown in the past 30 years. Table 1 shows experiments launched on "free-flying" satellites during the past three years and those planned for the near future.

Starting in the late 1980's, declining defense budgets drove STP to find less expensive, more efficient methods of fulfilling its mission. Furthermore, recent work force cuts have dictated performing the mission with fewer personnel. To cope with this reduction in financial and manpower resources, STP developed a new way of doing business.

We first describe the foundation of STP's "new way of doing business," which accepts greater management risk and increases reliance on contractor's best practices. This is demonstrated in the Space Test Experiments Platform (STEP) program. We then explain which technical aspects we expose to greater risk and the management practices we employ to minimize that risk. Throughout the paper, we describe both the successes and failures of our methods, and conclude with recommendations for future small satellite procurements in a depressed defense economy.

Mission (Contractor)	**Experiments (Sponsor)**	**Launch Vehicle**	**Launch**	**Comment**
ALEXIS (CTA/SS)	ALEXIS, BLACKBEARD (DOE) VSUME (USN)	Pegasus (OSC)	4/25/93	Success
RADCAL (CTA/SS)	RADCAL, SSPR (USAF)	Scout (LTV)	6/25/93	Success
STEP Mission 0 (TRW)	TAOS (USAF)	Taurus (OSC)	3/14/94	Success
STEP Mission 2 (TRW)	SIDEX (USAF)	Pegasus (OSC)	5/19/94	Success
STEP Mission 1 (TRW)	DUCTED, ADMS, PEA (USAF) CHAMPION, CADS, SETA (USN)	Pegasus XL (OSC)	6/27/94	Launch Failure
APEX (OSC)	PASP-PLUS, CRUX (USAF); FERRO (USN)	Pegasus (OSC)	8/3/94	Success
STEP Mission 3 (TRW)	SQUOD, EDMM (USAF) SAWAFE, ACTEX, SAMMES (BMDO)	Pegasus XL (OSC)	6/22/95	Launch Failure
REX II (CTA/SS)	REX II (USAF)	Pegasus XL (OSC)	2/29/96	First XL launch since '95 failure
ARGOS (Rockwell)	HTSSE II, USA, GIMI, HIRAAS (USN) SPADUS (USN); EUVIP (USA) ESEX, CIV (USAF)	Delta II (MD)	3/6/97	Now in Integration and Test
STEP Mission 4 (TRW)	OOAM (USN); EMPE, DIDM (USAF)	Pegasus XL (OSC)	6/8/97	Now in Build
TSX-5 (TBD)	STRV II (BMDO); CEASE (USAF)	TBD	TBD	Source Selection

Table 1: STP Recent Freeflyer Missions Launched or Under Development

II. INCREASED MANAGEMENT RISK

A. STEP--An Experiment in Acquisition Streamlining: Drastically reduced budgets and manpower drove STP to explore new ways of fulfilling its mission within tightening fiscal constraints. STP initiated the STEP program in 1989 in an effort to demonstrate that contractor's best practices could effectively replace restrictive government control. By giving the contractor greater control over the design, build, and test of the space vehicle, STP hoped to realize savings both in dollars and in the number of personnel required to manage the program. The contract was awarded in April 1990 to TRW Space and Electronics Group in Chantilly, VA, who subcontracted the satellite bus to CTA Space Systems (formerly DSI) in McLean, VA.

The STEP contract procured a series of small modular satellite buses whose components, largely off-the-shelf, could be assembled to meet the unique requirements of experimental payloads from the DoD-SERB list. As with most STP free-flying satellites, each STEP mission had a development timeline from contract award to launch of two to three years. The standard mission life for each bus was one year with a goal of three years. Where possible, the contract allowed using the contractor's best practices in lieu of military specifications and standards. Furthermore, program documentation and government configuration control were minimized. The contract type was fixed price with a periodic award fee during the design, build, and test phases of the program and a performance-based incentive to be collected during on-orbit operations.

B. Contractor's Best Practices: The shift to the contractor's best practices implied a significant reliance on the ability of the contractor to completely fulfill the mission requirements. The goal was to avoid imposing the usual collection of military specifications and standards and let the contractor use their own expertise to determine the most efficient manner of fulfilling those requirements. This reduced the government's role to one of an informed observer of contract performance.

In practice, conflicts arose whenever independent engineering and risk analyses performed by the Aerospace Corporation (a Federally Funded Research & Development Company supporting the Air Force Space & Missile Center) differed significantly from that proposed by the contractor. This most often occurred during box and system level testing. Disagreements arose over what was considered "good engineering practice". As the program progressed, the contractor found themselves overrunning proposed costs on the fixed price contract and became increasingly reluctant to heed government advice. When the government was unwilling to accept the risk of contractor's best practices, they directed the contractor to assume the government's approach. These increased program cost and the management effort required to accomplish the engineering changes.

C. Reduce Documentation and Configuration Control: Another streamlining effort reduced the number of contractually required documents. Large programs such as Global Positioning System (GPS) and MILSTAR have had more than 70 contractually deliverable documents. STEP has only 23 such documents. Wherever possible, the contractor's format is used instead of burdensome government format. When the government needs additional information, such as detailed drawings or test procedures, the contractor furnishes these documents upon request, but they are not subject to government approval, and are only used for information purposes.

Additionally, the government does not control the spacecraft configuration. The contractor maintains configuration control which is not subject to government approval. This gives the contractor the flexibility of changing design features of the spacecraft very quickly without waiting for a configuration control board to convene and approve the design change. However, this increases the risk of interface mismatches between the satellite and the payload, the launch vehicle, and the mission control center. To alleviate this risk, the government retains approval authority over the documents that govern these interfaces. In practice, reducing documentation and eliminating government configuration control has given the contractor greater flexibility and has resulted in cost savings without impacting the mission.

D. Contract Type: The contractual vehicle can also be matched to perceived mission risk. The fixed price STEP contract assumed the modular nature of the STEP vehicle would be a low risk effort, easily assumed by the contractor. To reward performance during the design, build, and test phases, the contractor received an award fee to reward their cooperation with the government program office and their responsiveness to the experiment teams. Once the spacecraft was on-orbit, the contractor earned incentive dollars based on pre-determined performance criteria.

In practice, the experimental payloads chosen from the DoD-SERB list had stressing requirements that often required significant modifications to the modular bus design. Furthermore, the contractor experienced developmental problems in the first two STEP missions that caused them to overrun their fixed price target. Since the contractor paid 100% of the overrun above a predetermined ceiling, when the overruns exceeded the available award fee, the award fee was not sufficient to encourage the contractor to cooperate with the government. However, in the later STEP missions, the contractor overcame these developmental issues and performed within cost and schedule goals.

By contrast, the Advanced Research and Global Observation Satellite (ARGOS) is on a cost-plus award fee contract. By selecting the cost-plus contract, the government had implicitly agreed to assume the greater risk of this one-of-a-kind satellite which will fly eight large complex experiments from the DoD-SERB list. The ARGOS contractor experienced significant developmental problems in the spacecraft electronics area, which led to large overruns absorbed entirely by STP.

Considering the experience with the STEP and ARGOS programs, it would appear that building the first in a series, or a one-of-a-kind small satellite, implies significant risk to the contractor designing the satellite from “scratch”. However, for a series of satellites, the developmental risks should decrease with each successive satellite produced.

III. MANAGING INCREASED MISSION RISKS

A. Use Non-Redundant Subsystems Where Possible: Most operational satellite programs have completely redundant subsystems to reduce the chance of a system failure terminating the mission prematurely. While complete redundancy is certainly effective, it can often carry severe penalties in cost and weight. For R&D satellite programs in STP, we reduce mission cost by using a “single string architecture,” which selectively uses redundancy to improve reliability in specific subsystems or components. We mitigate risk by performing extensive reliability calculations, and by using this data to prudently balance risk against cost in determining which subsystems to make redundant.

For example, the STEP transponders have 0.99999 reliability. Consequently, adding redundancy did not reduce enough risk to justify the cost and weight of a second transponder. On the other hand, the Attitude Control Subsystem (ACS) for STEP Mission 4 is a critical subsystem for meeting experimenter requirements. In order to meet these strict ACS requirements, we decided to add redundant ring laser gyros. This decision was also made because adding a second ring laser gyro did not significantly increase the cost or weight of the space vehicle. By trading mission risk against cost, we achieved a predicted overall STEP Mission 4 reliability of 0.911 for the required mission duration of one year.

B. Relax Test Requirements: Standard STP satellite test philosophy allows acceptance or protoflight testing in place of qualification testing whenever applicable. Acceptance tests performed at slightly above maximum predicted environments primarily demonstrate successful operation of the flight hardware and detect deficiencies in workmanship, materials, or quality. Detecting these deficiencies on the ground reduces the mission risk of “infant mortality” hardware failures during the early flight phase of the satellite. Protoflight tests verify design and workmanship. They are performed on flight hardware at higher stress levels than acceptance tests. Qualification tests mainly demonstrate design adequacy and are performed on non-flight hardware at higher stress levels than acceptance and protoflight tests.

increases. For example, restricting the temperature limits in the spacecraft thermal cycling test, in item (3) of Figure 2, to the limits of the most sensitive component would prevent a more hardy component from being tested through its own predicted operating range. Therefore, the components need to have been tested through their individual maximum predicted operating temperature ranges at the component level in item (1 b). Since the contract does not bind the contractor to meet testing requirements document MIL-STD-1540B, the contractor typically follows it only as a guide and combines it with their own in-house practices. Therefore, the space vehicle and its components often do not achieve the margins described in the military standard. This increases the risk of on-orbit failures if on-orbit conditions fall outside the bounds the contractor predicted during preflight analysis.

STP requires payload experiments to perform electromagnetic compatibility (EMC), thermal vacuum, and vibration tests on their instruments before delivery to the contractor for spacecraft integration. After integrating the experiments onto the spacecraft bus, the contractor conducts an Integrated System Test (IST) to demonstrate system performance and connectivity of the subsystems and payloads. Later, they perform a precompatibility test to verify communications compatibility between the mission control center and the space vehicle. The space vehicle then undergoes environmental testing consisting of EMC, thermal vacuum/balance, and dynamic tests. After environmental testing, the contractor performs another IST along with propulsion, mass properties, and spin balance tests. Testing for STP satellites is often not as thorough as the testing done for larger satellite programs. For example, the thermal balance test is performed in a thermal vacuum chamber using uniformly hot walls at the hot extreme and uniformly cold walls at the cold extreme instead of simulating solar radiation by using lamps and performing more thermal balance cases.

C. Use Minimal Staff for Operations: The total cost for a satellite mission involves not only space vehicle procurement, but also the cost of ground operations. This includes mission planning, orbit analysis, daily operations, post-pass analysis, and payload data collection. Unfortunately, the use of outdated technology and manpower intensive operations concepts have typically driven operations costs very high. By using the latest in COTS products and changing our operations concepts, we have significantly reduced ground operations costs.

Previous satellite control systems used 1970’s mainframe technology which required many personnel for operation and maintenance. New command and control centers are composed of the latest available COTS hardware and software. Distributed processing, open architecture, and user friendly interactive displays typical in today’s COTS products have enabled operations centers to “do more with less. ” Previously, a staff of up to twenty people performed analysis functions for STP programs. The new work-station based system requires no more than eight people to accomplish the same tasks.

Traditional operations concepts focused on eliminating mission risk altogether. This was done by staffing experienced personnel 24 hours per day, and by having two or three different people manually check all critical commands and operations sequences. The use of expert systems has allowed staff levels to be cut significantly. Instead of relying on manual independent checks of data and commands, we now rely on user programmable expert systems to check telemetry data and send commands. This reduces the number of personnel required for a satellite contact from four to just one. Furthermore, specific satellite expertise used to be spread evenly across all duty shifts so that there would always be personnel available for mission planning and anomaly resolution. Experience has taught us, however, that we can still maintain very low mission risk by performing all planning functions on day shift. The mission experts are merely on call during off-shifts.

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We have discussed how budget constraints and fewer management personnel result in higher risk missions. However, we still maintain effectiveness by focusing our limited management resources on the program areas which historically evidence the greatest risks to cost and schedule, namely the interfaces between the spacecraft, the payload, the launch vehicle, and the mission control center.

IV. RISK MITIGATION--FOCUS ON THE INTERFACES

A. Experiment to Spacecraft Interface

1. Standardize the Payload Interface: To reduce cost and risk, STP has attempted to clearly define a standard payload interface for all DoD-SERB ranked experiments. This approach has been most successful in establishing the MIL-STD-1553B data bus and 28 V DC power bus as STP standards. However, it has proven difficult to standardize other aspects of the interface because of the diverse attitude control, thermal, mechanical, and deployable requirements levied by the complex experiments on this list.

2. Develop Payload Requirements Early: During space vehicle development, the government retains the greatest influence over the interface between the experiment payloads and the spacecraft bus. Because experiment packages are designed and built by various organizations, usually to different schedules, the program office must aggressively manage this interface as hardware is built and tested. We accomplish this by developing an Experiment Requirements Document (ERD) prior to putting the space vehicle on contract. The ERD outlines the top-level demands an experimenter places on the space vehicle.

As the design matures, the top-level ERD requirements evolve into an Interface Control Document (ICD) which defines the detailed physical, mechanical, electrical, thermal, and communication interfaces the experiment agency, government program office, and space vehicle contractor agree to meet. Even though experiment requirements evolve throughout the program, early definition of all basic experiment requirements is vital for the contractor to accurately bid the program and to begin preliminary design. It also helps minimize the magnitude of mismatches during interface verification, when changes pose significant cost and schedule risks.

3. Verify Payload Interface Before Integration: Before shipping the experiments to the spacecraft contractor’s facility for spacecraft integration, the program office conducts an Interface Verification Audit on each experiment. During this audit, we thoroughly review the as-built mechanical and electrical interfaces, and compare them to the ICD. This is performed for both sides of the interface -- experiment and spacecraft. We document all instances where the experiment or spacecraft does not comply with the ICD and resolve these prior to experiment shipment. This mitigates possible schedule and cost impacts that would arise if interface mismatches are not discovered until the payload arrives at the spacecraft contractor’s facility.

B. Launch Vehicle to Space Vehicle Interface: We handle the interface between the launch vehicle and the space vehicle in a similar manner, with the government managing the requirements development phase to keep risk at acceptable levels. We capture launch vehicle and space vehicle requirements as they develop in the Launch Vehicle to Space Vehicle ICD (LV ICD). The LV ICD also defines the launch environments and interface descriptions.

C. Mission Control Center to Space Vehicle Interface: The third mission-critical interface we focus on is between the space vehicle and the mission control center. An interface mismatch could delay the ground database development effort, or even more critically, cause command and telemetry transmission problems with the space vehicle on-orbit. To prevent these problems, we manage this interface through a space vehicle to mission control center ICD. On the vehicle side, the ICD documents database delivery schedules and how the vehicle accepts and receives data. This allows the ground database developers to create products in the proper format. On the ground side, the ICD documents Air Force Satellite Control Network (AFSCN) and control center data transmission protocols, data rate limitations, and frequency utilization so the spacecraft can receive and transmit data in an acceptable format. Once the ground system and spacecraft are fully developed, we perform end-to-end compatibility tests to verify all the communication links between experiments, spacecraft, AFSCN, and control center.

V. CONCLUSIONS

The Space Test Program will launch into the next century with streamlined acquisition practices to complete their mission with fewer resources than ever before. These practices involve decreasing the government’s role in managing the spacecraft development and relying more on contractor’s best practices for building the spacecraft, The contractor can accomplish this task at a reduced cost if the government reduces the need for contractually deliverable documents and government-managed configuration control. This streamlining effort comes at the cost of increased mission risk. However, as demonstrated here, there are effective methods of managing this risk.

One set of risk management techniques relies on making intelligent compromises during the spacecraft development. STP missions, usually being Class C spacecraft as defined by DoD HDBK 343, can afford to sacrifice system redundancy where allowed by the reliability requirements. Test requirements can also be relaxed, such as reducing the amount of qualification testing. Finally, cost savings can also be realized by using work station based operations centers that reduce the staff necessary to support operations.

Another set of risk management techniques focuses management attention on the spacecraft interfaces (to payload, launch vehicle, and mission control center) and lets the contractor build the spacecraft using their own best industrial practices. The contract type best fitted to this situation is the fixed price contract, with performance oriented award fees or incentives. However, as contractors bid for these fixed price contracts, they must keep in mind that one-of-a-kind spacecraft programs typically encounter developmental problems that can lead to overruns.

The Tri-Service Space Experiments (TSX) program represents the latest STP initiative in streamlining the acquisition process per the latest DoD directives. TSX goes beyond the STEP contract in granting autonomy to the contractor. This firm fixed price contract assigns the contractor the responsibility to provide the spacecraft as well as, potentially, the launch service. TSX also allows the bidding contractors to determine the percentage of total contract dollars they are willing to assign to the on-orbit incentives. This new concept transfers much of the risk management effort from the government to the contractor. Currently under source selection, we expect that TSX-like practices will successfully carry STP into the next century of tight DoD space budgets.

We understand that these techniques are not applicable to those programs that cannot tolerate increased mission risk. But for the category of research and development satellites that typically run on tight budgets and do not perform the critical missions of the Class A and B satellites, we recommend these risk management techniques for maintaining mission performance within the limitations of today’s tight financial resources.