The Space Congress® Proceedings

1996 (33rd) America's Space Program -What's Ahead?

Apr 25th, 1:00 PM - 4:00 PM

Paper Session III-B - The Space Test Program, A Case for Dedicated Research, Development, Test and Evaluation in Space

Roald F. Lutz
USAF, Space Test Program

Richard M. Macheske
Space Test and Experimentation, The Aerospace Corporation

The Space Test Program,
A Case for Dedicated Research, Development, Test and Evaluation in Space

Major Roald F. Lutz, USAF
Space Test Program
Los Angeles Air Force Base; USA
1.310.363.6778

Richard M. Macheske, Jr.
Space Test and Experimentation
The Aerospace Corporation; USA
1.505.846.8387

02 January 1996

Abstract

Soon after the first space launches, it became apparent that space systems could provide unique services; but how would new space technologies and concepts be developed and tested? In 1966, the U.S. Department of Defense (DoD) established the Space Test Program (STP) for which the Department of the Air Force was named the executive agent. STP is chartered to provide space flight opportunities for DoD relevant science and technology experiments lacking other means of space flight. From 1967 to the present, STP has provided space flight for more than 370 research and development payloads in a cost effective manner using various methods including: unique satellites on dedicated expendable rockets, the Space Shuttle, and secondary opportunities on larger missions. STP has enhanced DoD operability by: improving operational and pre-operational designs, applying needed capabilities prior to the existence of operational systems, reducing the development risk for pre-operational payloads, increasing knowledge of the space environment and discovering unanticipated benefits. The execution of the STP mission has been shown to be a better, faster, cheaper means of enhancing DoD space technologies.

I. Introduction

Since 1966, the Space Test Program has supported the DoD space research community by providing unique space flight testing opportunities for experiments whose objectives range from basic research to advanced development. STP missions have proven to be one of the most cost effective ways to flight test new space systems technologies, concepts, and designs. These missions provide an inexpensive way to:

1. Demonstrate the feasibility of new space systems and technology

2. Improve operational designs through exploration and characterization of the space environment and sensor physics.
3. Provide early operational capabilities for proposed systems
4. Perform operational risk-reduction through direct flight test of space prototypes
5. Develop the knowledge base from which to plan new and improved operational systems and system upgrades
6. Exploit unanticipated discoveries and opportunities.

The Space Test Program provides the only substantial DoD space flight capability to perform fly-before-buy demonstrations of advanced technologies in an operational space environment. The benefits gained over the now 30 year extent of this program, prove the value, relevance, and need for dedicated Research, Development, Test and Evaluation (RDT&E) in space.

II. The Program

The space research experiments flown by the Space Test Program are justified, developed, and delivered by the Service laboratories and DoD agencies to improve current and future operational space systems. More than 370 experiments have been flown since 1967 in support of operational missions including communications, navigation, weather, surveillance and reconnaissance.

As of October 1995, 112 missions had been launched, of which 101 were placed in orbit, for a long term launch success rate of over 90%. Once on-orbit, more than 83% of the experiments have been successful and have accomplished more than 50% of their objectives. More than half of all experiments orbited by STP have successfully accomplished 100% of their goals! This is an outstanding accomplishment considering the "one-of-a-kind" and "beyond the state-of-the-art" nature of space RDT&E experiments.

Experiments are considered for STP missions based on the priority assigned by the DoD tri-service Space Experiment Review Board (SERB). This board is independent of the STP Program Office and is made up of space requirements experts from the Air Force, Army, Navy, NASA ARPA and the Ballistic Missile Defense Organization (BMDO). STP is given the resulting prioritized list of experiments and then seeks out the most cost effective means of space flight to fly as many experiments as possible, given the constraints of priority, opportunity and finding.

The most common space flight opportunities include "piggybacking" as secondary payloads on existing, foreign or domestic military or commercial satellites, and flight of some experiments on virtually every Space Shuttle mission. Other experiments are flown as dedicated satellite missions as determined by available finding and compatibility of experiment requirements. This includes both small and medium launch vehicle class satellites. STP procures the spacecraft or satellite bus, but does not find experiment development. Typically, STP provides for one year of on-orbit operations. Extended operations past the first year are paid for by the experimenter or experiment sponsors. STP procures small launch vehicles if required, but does not procure medium launch vehicles directly. Medium launch vehicles are supplied by a different organization of the Air Force, currently, one every four to five years.

The Air Force, as the premier space service, funds the Space Test Program to act as an impartial broker supporting all DoD users. STP operates as a "level of effort" program, to gain the flexibility necessary to take advantage of the most cost effective means of space flight available for given complements of experiments. If a particular manifested experiment fails to maintain schedule, or is deemed impractical to fly, or if the envisioned space flight opportunity does not materialize, STP shifts what resources remain to fly the next highest priority experiment(s).

This flexibility is essential to deal with the volatile and fast-paced development of RDT&E space experiments and to capitalize on "missions of opportunity". These include opportunities for rides on operational spacecraft where excess weight margin is available. STP's ability to quickly react to opportunity ensures that the greatest amount of DoD space RDT&E is accomplished with the limited finds available.

The Space Test Program provides an extremely cost effective capability to launch and test new technologies prior to their initial incorporation into the United States' very expensive and demanding operational space systems. STP provides a center of excellence, alleviating the need for each Service and DoD agency to create individual capabilities in an attempt to duplicate STP's low-cost, risk mitigating capability.

STP capitalizes on the contractual economy of scale that a single space test organization provides, and the filtering function of the DoD tri-service Space Experiments Review Board assures minimum duplication and maximum synergy of space research and development experiments.

II. The Payoff

The benefits of STP have been broken down into six broad categories. Space, time and classification do not permit a fill recounting of all the benefits reaped by STP missions over the years. The following paragraphs provide some of the highlights of approximately two dozen STP missions as representative examples of their value and accomplishments.

A note on nomenclature; the Air Force naming convention for STP missions can be decoded as:

- P91-l; the "P" stands for free flyer project; 91 is the year started; -1 means the first project of that year (Prior to 1986, the two-digit year was the estimated launch year).
- S81-1; the "S" stands for secondary or piggyback missions.
- AFP-675; stands for Air Force Program number 675, referring to dedicated shuttle missions.

Demonstrate Feasibility

P72- 1 flew a demonstration thermal control coating to test durability and effectiveness. The successful test led to use on a number of military satellites, including the Defense Satellite Communications System (DSCS).

P74-1 The Lincoln Experimental Satellites 8/9 (LES 8/9) demonstrated EHF spread-spectrum anti-jamming communication technology, LES 8/9 demonstrated in space a second generation, reliable and survivable tactical communications system. The experiment demonstrated an advanced prototype military communications system using K-band frequencies. This became the basis for MILSTAR and the operational transponder carried by DSCS III satellites.

P78- 1 flew a suite of Gamma-ray, X-ray, and particle instruments to characterize the space environment. This mission demonstrated that high resolution gamma-ray spectrometers need even greater resolution to measure RORSAT emissions. This type of finding shows how feasibility demonstrations that do not succeed can be as valuable as those that do. Proving the infeasibility of a concept with a proposed technology can head off the extremely expensive development and deployment of an operational system based on faulty assumptions.

S80-1 The Fiber Optics in Space experiment that flew aboard the Long Duration Exposure Facility (LDEF) demonstrated and validated the use of fiber optics in space. The data gathered made a major contribution to plans to use fiber optics on the Space Station Freedom and will be a key component of the upcoming MIL-STD-1773 fiber optic data system. This is a key example of how STP provides extremely useful information for all space agencies.

S81-1 and P87-2 successfully demonstrated store and forward communication systems. These missions demonstrated technology that became precursors to operational store and forward communication systems including TDRSS.

AFP-675 (STS-39) The Cryogenic Infrared Radiance Instrumentation for Shuttle (CIRRIS) demonstrated feasibility of over the horizon IR surveillance techniques as a precursor to Space Based Infra-Red Systems (SBIRS). SBIRS must be able to discriminate between IR emissions of the target and natural background IR emissions of the upper atmosphere. CIRRIS results significantly revamped IR background models to help determine the best surveillance wavelengths. The background data will be used on upcoming operational IR surveillance systems.

CRRES The Combined Release and Radiation Effects Satellite demonstrated and evaluated a new high efficiency solar panel.

P91-1 Advanced Research and Global Observation Satellite (ARGOS); in 1997 this mission will demonstrate:

1. The suitability of High Temperature Superconductivity (HTS) space subsystems. HTS has been selected as one of the DoD's top 10 critical technologies with the potential for major breakthroughs in spacecraft operational capability. HTS digital technology offers more than 10 times higher speed then Si or GaAs. Factors of 100 to 1000 in power reduction and a 10 times reduction in weight are feasible. The High Temperature Superconductivity Space Experiment (HTSSE II) will space qualify HTS digital and RF components, parts, and subsystems to demonstrate in space the feasibility of this new technology. HTSSE II results will enable DoD spacecraft designers to evaluate the benefits of HTS components and subsystems for future spacecraft. An advanced cryo-cooler (which could be used for focal plane arrays and cooled semiconductors as well as HTS devices) will be demonstrated. Space radiation effects and survivability of HTS devices will also be measured. The operation of multiple semiconductor devices at high superconductivity temperature (77°K) in a space environment will also be demonstrated.
2. Large scale (26 kW) electric propulsion performance and EMI compatibility. The Electric Propulsion Space Experiment (ESEX) will prove the feasibility of high-power arcjet propulsion, a crucial technology needed to support cost effective access to space. ESEX will demonstrate orbit transfer,

circularization, and adjustment, verify compatibility with spacecraft subsystems, and space qualify the largest power system ever orbited (26 kW). ESEX will demonstrate reliable arcjet thruster operation in space without interfering with electrical, thermal, or contamination constraints of the host spacecraft. Electric propulsion will double the payload-to-orbit capability of an Atlas II and make it possible to use an Atlas or Delta instead of a Titan IV for many high orbit altitude payloads, reducing launch costs by a factor of ten. Electric propulsion also addresses the DoD space lift and maneuvering requirements (including station-keeping) for global surveillance and communications orbits and the application of advanced technology in order to reduce life cycle costs. MILSATCOM has expressed interest in arc-jet thrusters for advanced communication satellite systems.

3. Autonomous S/C navigation using x-ray stars. The Unconventional Stellar Aspect (USA) experiment will demonstrate the feasibility of astronomical X-ray sources for potential use as autonomous position, attitude, and time keeping references for military space systems. This has the potential to replace GPS timing and navigation with an invulnerable natural source (pulsars). USA will also perform the first X-ray tomographic survey of the earth's atmosphere. The experiment will track and measure periodic celestial X-ray sources on orbit, providing extremely precise timing resolution critical for autonomous navigation. USA combines the re-flight of detectors flown successfully on the short-duration NASA Spartan- 1 mission with state-of-the-art processor technology for data handling and time/position determination. USA will demonstrate the first orbital test of three radiation hardened 32-bit space computers developed by BMDO for Brilliant Eyes and other applications. The computers will be space qualified by performing real-time navigation computations in a legitimate space radiation environment. The augmentation of a proven X-ray detector design with advanced computers will help demonstrate the feasibility of autonomous satellite navigation.

Improve Operational Designs

S67-3 Measured the spectral variation in the Earth's background radiation in the IR spectrum. This provided needed background measurements for DSP's spectral filters allowing better background filtration to improve sensor signal-to-noise sensitivity thus improving the operational design.

S69-4, S70-4, P70-2 and P72-1 successfully flew a series of ballistic shapes at acquisition altitudes for checkout and calibration of ground radars.

P78-2 Spacecraft Charging at High Altitude (SCATHA) operated in geosynchronous orbit for over 12 years. SCATHA's results explained the anomalous temperature rise of SDS radiators and the anomalous degradation of Block I GPS solar arrays. The cause was warm surface contamination, which was not believed significant until that time. GPS and another satellite system used this information to improve the design of later blocks of operational satellites.

SCATHA also performed 14 experiments related to spacecraft charging. Results were used in analyzing operational system anomalies and in creating military standards for spacecraft charging. One operational user paid for 3.5 years of continued operations to gain data on charging anomalies, thereby showing the confidence in and usefulness of the experiment to improve their operational design. Changes were also made to DSP satellites in light of SCATHA's charging anomaly data. SCATHA's charging discoveries effected virtually all subsequent high altitude satellite mission designs.

SCATHA also investigated degradation of thermal control coatings in orbit. This led the SDS program to change their plan to coat mirrors with a specific conductive coating after the on-orbit test proved it unsuitable.

P86-1 The Combined Release and Radiation Effects Satellite (CRRES) space qualified advanced microelectronic components in a known space radiation environment. It discovered a new radiation belt that caused Brilliant Eyes, now the Space Missile Tracking System (SMTS), to change their planned orbit to a lower radiation dose orbit. CRRES' Single Event Upset (SEU) findings caused a classified user to revamp its entire electronics approach.

AFP-675 (STS-39) The Cryogenic Infrared Radiance Instrumentation for Shuttle (CIRRIS) characterized background signatures of JR emissions in the upper atmosphere. These background clutter results caused the Space Missile Tracking System (SMTS) to add a previously unplanned medium wave IR filter wheel.

P87-1 Polar Bear defined requirements for DMSP's UV cross-track scanning instrument (SSULI), planned for launch by the end of the decade.

P95-2 Tri-Service Experiments 5 (TSX-5) will improve operational space systems design through direct feedback from flight test of the Space Technology Research Vehicle 2 (STRV-2) experiment.

STRV-2 will evaluate materials, contamination effects, IR filter technology, microelectronics and meteor/debris environment for potential Space Missile Tracking System (SMTS) applications. This experiment will provide valuable design feedback into SMTS, even though the experiment is not considered a "fundable" part of the SMTS program. STRV-2 is a separate BMDO sponsored experiment that support SMTS-type technology. STRV-2 will improve operational designs through evaluation of multi-agency and multi-national components and operations. More than 1/4 of the cost of the STRV-2 payload is paid by cooperative United Kingdom space finding.

Provide Early Capabilities

P67-2 Lincoln Experimental Satellite 6 (LES 6) provided the only US military UHF satellite communications service from 1972-1976. This mission led to the current operational FLTSAT-based tactical communications system.

P74-1 The Lincoln Experimental Satellites 8/9 (LES 8/9) while demonstrating EHF spread-spectrum anti-jamming communication technology, also provided a limited MILSTAR-type, reliable and survivable tactical communications system. This allowed MILSTAR terminals to become operational years before the first MILSTAR satellite launch.

S81-1 and P87-2 While demonstrating store and forward VLF communications capability, S81-1 and P87-2 also provided a limited store and forward operational communications capability prior to the completion of operational systems.

P91-1 Advanced Research and Global Observation Satellite (ARGOS); in 1997 this mission will provide an early flight of the DMSP "SSULI" UV sensor. This mission will provide proof of concept and early meteorological data three years before the operational sensor is launched on DMSP.

Perform Operational System Risk Reduction

P73-3 TIMATION 3 successfully flight tested Cesium & Rubidium atomic clocks as a major risk-reduction contribution to the Global Positioning program.

P76-4 Navigation Technology Satellite 2 (NTS-2) continued GPS research in space, actually becoming the prototype for the GPS/NAVSTAR system. NTS-2 allowed early risk-reduction test of the GPS Block I ground control system and software. NTS-2 also verified software and tracking techniques before launch of the operational GPS system.

S82-1, P83-1 and P86-1 improved space weather forecasting for the warfighter so that operational systems effectiveness could be better predicted under different solar and orbital conditions. Space weather forecasting allows operational systems to prepare for and react to radiation events. Better prediction will reduce risk to these vital space systems.

P87-2 STACKSAT provided the first flight of a large solid state data recorder, now the industry standard for on-orbit data storage. Failure of old technology tape-recorders was often a significant cause of mission failures. These failures can now be avoided entirely with solid state technology that is extremely robust and degrades gracefully. This is a good example how multiple agencies benefit from STP RDT&E.

P91-1 Advanced Research and Global Observation Satellite; in 1997 this mission will fly prototypes of three BMDO 32-bit flight computers (USA experiment) and DMSP'S not yet operational SSULI UV sensor (HIRAAS experiment). Early flight test of these advanced components will reduce risk in future operational systems that will use them.

P95-2 In 1998 the Tri-Service Experiments 5 (TSX-5) will perform operational space systems risk reduction by space-qualifying a highly instrumented engineering prototype of the soon to be operational Compact Environment Anomaly Sensor (CEASE).

The Compact Environment Anomaly Sensor is planned for DMSP follow-on and envisioned for possible MILSATCOM use if validated by STP. The generic capability will serve any satellite in high radiation environments. Currently, the local satellite radiation environment is usually predicted from the ground and activities are planned around severe radiation "events". With practical, autonomous, in-situ satellite based radiation sensing and diagnosis, radiation events can be quickly reacted to; saving data and preventing damage or even loss of important on-orbit assets.

Knowledge Base Development

This category is the backbone of all STP activities. All RDT&E systems in some way advance the understanding of the space community. The following examples will be very specific highlights and by no means comprehensive.

P72-1 hosted a suite of Gamma-ray and radiation sensors to characterize the atmosphere and provide background data for surveillance satellite design. The mission also measured charged particles in the lower ionosphere and contributed to understanding ionospheric effects on communications. Spacecraft observations contradicted earth-based meteorological predictions and caused the prediction methods to be revised.

P78-2 The Spacecraft Charging at High Altitude (SCATHA) mission provided a wealth of discoveries, including:

1. New discoveries concerning the space radiation environment. SCATHA proved previous gee-synchronous radiation predictions wrong by an order of magnitude. This led to the creation of a new standard space environment for USAF space vehicles at gee-synchronous altitudes.
2. Vastly expanded understanding of spacecraft charging effects. SCATHA conclusively proved that anomalies can be caused by spacecraft charging. Specific design guidelines were created for gee-synchronous satellite discharge immunity. Anomaly diagnoses were performed on essentially all operational space systems using this valuable STP data.
3. Improved understanding of contamination processes. SCATHA brought the realization that even warm sunlit surfaces accumulate significant amounts of molecular contamination. To date, at least 50 organizations have requested this data for their design use and understanding.

P91-1 Advanced Research and Global Observation Satellite (ARGOS); in 1997 this mission will characterize the upper atmosphere and ionosphere using one X-ray sensor and six ultra-violet (UV) sensors. It will also characterize the debris and radiation environment in a highly populated DoD orbit.

The High Resolution Airglow and Auroral Spectrograph (HIRAAS) is a multi-instrument experiment package containing three ultraviolet spectrographs to measure naturally occurring atmospheric emissions.

The Global Imaging Monitor of the Ionosphere (GIMI) experiment is a follow-on to the short duration, Shuttle-bay, Far UV, film-based cameras which established the feasibility and utility of far UV imaging on the earlier AFP-675 program. GIMI will demonstrate operational CCD sensor technology for environmental monitoring of upper atmospheric perturbation due to meteors, rocket exhausts, and aurora. Use of wide-field sensors in three separate wavelengths will enable GIMI to continuously image 350 square nautical miles areas of the Earth’s limb.

When integrated over the entire polar orbit, this will provide DoD users with an improved capability to obtain global ionospheric space weather coverage. GIMI’s significantly increased mission duration, wide-field coverage, and CCD technology will provide substantial improvements to our knowledge of the ionosphere, and aid in detecting unpredictable events such as rocket launches.

The Extreme Ultraviolet Imaging Photometer (EUVIP) will establish the behavior of the upper atmosphere and plasmasphere as needed for Army RF systems design, including prediction of magnetic storms and characterization of the aurora. This data will improve existing data bases of background intensity levels against which rocket plumes can be observed. EUVIP will observe the earth horizon and stellar environment to measure background radiation and provide information on variations in space and time for future sensor design. The end product will be an improved model for predicting effects of the upper atmosphere on communication systems and eventually a "weather" prediction of the upper atmosphere for operational use.

The Critical Ionization Velocity (CIV) experiment will release Xenon and $C0_2$ to study ionization processes caused by molecular collisions in the upper atmosphere. The results will be used to help identify plumes and atmospheric wakes of launch vehicles. This experiment will improve on an existing CIV data base by using ground sensors to observe releases performed at a greater orbital velocity and with ten times the release volume of previous attempts. This also allows assessment of existing ground sensor performance, possibly eliminating the need to develop future sensors.

The Space Dust (SPADUS) experiment will provide definitive measurements of orbital debris in a highly populated DoD orbit. SPADUS responds to key operational needs for space survival set forth in the 1987 DoD Space Policy. SPADUS also supports the National Space Council's call for speed-up of work to characterize orbital debris. This effort will result in a 3-D survey map of the present dust distribution in low earth polar orbit and allow prediction of orbital debris "showers" which could affect DoD spacecraft, the Space Shuttle, and Space Station. SPADUS also includes ancillary diagnostics to measure the local radiation environment. Experiment results will improve the design database for spacecraft shielding and electronics; extending space vehicle lifetimes.

SPADUS will also obtain early flight experience for sensors and electronics which are planned for Space Station Freedom and the Cassini mission to Saturn in 1998.

Exploit Unanticipated Discoveries and Opportunities

P74-1 Lincoln Experimental Satellite 8/9 (LES 8/9) as a secondary objective, demonstrated four techniques to locate from orbit, sources of radio frequency interference (RFI). These detection techniques were deemed valuable enough that the US Navy established an operational capability for UHF RFI source location. Although this discovery was unanticipated, it proved to be highly useful.

AFP-269 (STS-4) discovered the heretofore unknown degrading effects of atomic oxygen on widely used thermal blanket materials. This resulted in whole classes of thermal blanket materials being deemed unusable, and the development of new materials

AFP-675 (STS-39) The Far Ultraviolet Cameras experiment and the Horizon Ultraviolet Program experiment discovered a much sharper than expected UV horizon. This has potential applications for much improved horizon sensors since the UV horizon is lower and sharper than the currently used IR horizon.

IV. The Future: Space Based Radar (SBR) as an Example:

Space Based Radar is a future operational space system that will replace or supplement the current AWACS warning and control mission with a space based system with worldwide coverage. SBR is planned for deployment in 2015 and has identified six critical technology needs. STP is already proving three of these technologies:

1. Advanced power and distribution. The P91-1 ARGOS mission will fly an advanced nickel hydrogen battery as part

of its 1000W orbital average power system. ARGOS will also space qualify the largest power system ever orbited (26 kW for 15 minutes).

2. High efficiency electric orbit transfer stage. The P91-1 ARGOS mission will fly the ESEX 26 kW arc-jet to prove its compatibility and use as an orbit transfer stage.
3. Radiation tolerant electronics and solar cells. The P91-1 ARGOS mission will flight qualify tree different radiation hardened, 32-bit flight computers. The P90-6 Advanced Photovoltaics and Electronic Experiments successfully tested advanced electronics and solar cells in an extreme radiation environment. The S90-3 CHARGECON-GEO experiment on-orbit today, provides early warning of solar events and will further develop spacecraft charging databases that will apply to high energy orbital radar emitters. P95-2 (TSX-5), described earlier, will also space qualify a radiation sensing and diagnostic package that will allow autonomous quick-reaction to radiation events.

In addition to these existing missions, there are three more experiments on the current 1995 tri-service Space Experiments Review Board priority list that support SBR objectives, with more to come in future years.

V. Conclusions

The payoff of RDT&E flight test in space has truly been astronomical. Proof (and disproof) of feasibility have shaped operational space systems that support the warfighter and the civil community alike. Operational designs have been optimized using the results of STP missions and valuable risk reduction has been performed. Limited early operational capabilities have been provided both as useful on-orbit assets and as an educational tool for operators and system planners.

Risk to operational systems has been reduced through early space hardware testing and technique development. The knowledge base of technology, orbital environment and sensor phenomenology has been vastly enlarged. Finally, unanticipated discoveries have led in new directions for space system capability never imagined or planned into regular operational programs. The Space Test Program has led the way, often as much as 20 years in advance of the operational world, and remains the cornerstone of DoD RDT&E in space.

REFERENCES

"The Air Force P-675 Shuttle Mission: Space Science in the Department of Defense", Dr George Carruthers, Naval Research Laboratory, October 1988

"Space Test Program Contributions to DoD Operational Programs", The Aerospace Corporation, March 1991

"A Brief History of the DoD Space Test Program", International Aerospace Division Note (IADN) 94-2, Thomas Hagler, Dr Eva Czajkowski, ANSER Corporation, Dec 1993