SINGLE PURPOSE SATELLITE SYSTEMS

by

Warren S. Watkins/ CTA INCORPORATED
ABSTRACT

This paper examines the need for tactically responsive space systems capable of supporting battlefield and fleet commanders. Terminology used to describe this category of satellite system varies according to organization or agency. The Defense Advanced Research Projects Agency's Lightsat, the Naval Space Command's SPIN-SAT, and the Air Force Space Command's TACSAT, are reviewed. The United States Space Command's space support mission is addressed and the role single-purpose satellites can play in fulfilling requirements for operationally responsive satellite systems is described. The United States Department of Defense space policies are discussed. The position taken by Secretary of Defense, Frank Carlucci regarding CHEAPSATS is discussed. The relationship between multi-mission and single-purpose satellite systems is delineated, in addition to fulfilling specific mission requirements, single-purpose satellite systems can augment multi-mission systems in crisis or fill temporary outages. Candidate functions for single-purpose satellites which include: communications, surveillance, meteorology, and store and forward (to readout remote sensors or transfer data to forward users) are discussed.

This paper identifies major factors which have contributed to the high cost of today's satellite systems and suggests: 1) modifying or eliminating military standards which are no longer applicable in light of today's modern highly reliable technology; 2) eliminating the requirement for redundant systems where operational requirements clearly do not warrant them (i.e. a tactical system required to support a battlefield commander for six months does not require redundant systems to provide three year life expectancy); 3) maximizing the use of commercial-off-the-shelf equipment; and 4) adapting best commercial practices during development. A new philosophy regarding testing and reliability is provided. This philosophy is required to make single-purpose satellite systems cost effective.

Reducing the production costs of single-purpose satellite systems will not guarantee an inexpensive system since launch costs constitute a major portion of a system's overall cost. The smallest launch vehicle available today is the 1950's technology Scout, with a launch cost of approximately $10 million. New launch technology such as that used in the Pegasus launch system can reduce burdensome launch costs. The current vertical launch integration philosophy and capabilities are not responsive to operational requirements.

Horizontal launch integration methods and new launch systems derived from commercial ventures have the potential to make space systems more responsive to tactical commanders as well as decreasing total system cost.

A systems approach to meeting operational requirements should be incorporated into architectures and operational concepts. This approach would take advantage of symbiotic relationships which exist between today's systems and future single-purpose systems. Planning should emphasize the day-to-day use of a set of these single-purpose systems to ensure operational personnel are proficient. Single-purpose satellites have the potential to profoundly impact the use of space systems by tactical commanders in the theater environment.
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INTRODUCTION

Within the last two years, there has been a resurgence of interest in Single Purpose Inexpensive Satellite Systems (SPINSATS), reference the recent compromise between DARPA and the Air Force regarding DARPA's Lightsat program which calls for DARPA to down play work on launchers and concentrate on low-cost satellite technology. DARPA is pursuing Lightsat Research and Development (R&D), an area previously dominated by the Air Force. Organizations/agencies have different terminology for small satellite systems. The Navy uses the term SPINSAT, the Defense Advanced Research Projects Agency (DARPA) refers to this class of satellites as Lightsats, recently the Air Force Space Command (AFSPACECOM) has begun to define this class of satellites as Tactical Satellites (TACSATS), another term which has been used is CHEAPSAT. The former Secretary of the Air Force Edward C. Aldridge Jr. was of the opinion that cheap satellites could not be built to perform the missions of today's large multi-mission space vehicles. Today's technology does not allow all the functions of large satellites to be packaged into a small satellite. However, there are several reasons why small satellites are gaining in popularity and may become the systems of the future. The Wall Street Journal carried an article in their February 9, 1989 issue which discussed activities in the small satellite area. One of the more noteworthy items in the article was a reference to Senator Robert Byrd's (D W. VA) space symposium held in January of this year. Senator Byrd sees small satellite development as a "hot new industry essential to national security and international competition."

The 1987 revision to the 1982 DoD Space Policy recognized that space was a medium just like land, sea, and air in which military operations may be conducted for force enhancement and force application. Control of space is a vital element of the new space policy. Control of space means the freedom to operate systems in space and the capability to deny an adversary the ability to operate in space when the need arises.

To the average field commander, satellites tend to be viewed as fragile, non-survivable, non-responsive, temperamental systems which cannot be relied upon in time of conflict. Proliferation of satellites is a method of increasing survivability and adding robustness to a space system. The cost of today's satellites make proliferation highly unlikely, although the Global Positioning System (GPS) does rely on a proliferated constellation of 24 satellites to achieve robustness at a cost of several billion dollars. GPS fulfills responsiveness requirements by having a large number of satellites in orbit. An alternative to maintaining a large number of satellites in orbit to meet responsiveness requirements is to have a responsive launch capability and spacecraft available for launch.

Space systems have been supporting the military warfighting commanders for many years. Only recently have these warfighting commanders been made aware of the


2. The term SPINSAT has been used by Dr. William E. Howard, III, Director of Technology, Naval Space Command, for several years. Dr. Howard is the first person I know to have used the term.


capability which could be provided to them. In the past, the battlefield commander has taken what information has been provided to him and made the most of it. Today those same battlefield commanders are asking for organic space resources. Additionally they want those space resources to be responsive to their needs. Small satellite systems have the potential to fulfill the growing requirement for responsive, organic space assets [organic in the sense that the space system appears to be dedicated to the commander while the satellite is over his Area of Responsibility (AOR)].

Current technology makes it possible to package a single function into a relatively small mass. New technology developments in charged coupled devices (CCD), mosaic sensor arrays for different spectrums, compact high speed computers for on board sensor processing, more efficient power generation capabilities, and image compression techniques to decrease the data rates on existing communications links will allow small single purpose satellites to be produced with off the shelf technology/equipment. Mobile ground terminals consisting of powerful, compact computer systems capable of providing satellite commanding and mission data processing can be developed using existing technology to support the small satellites of the future. These systems could be deployed to theater level commanders.

Launching space assets has been an expensive proposition in the past, new innovative methods of achieving orbit will change this. The requirements of the battlefield commander has not been a driving factor in our launch strategy. This is changing, the USSPACECOM is conducting an Assured Mission Space Support Architecture Study (AMSSAS). This study will define the requirements of the battlefield commanders. It is expected that these requirements will lead to a responsive launch strategy and resulting launch assets. Achieving this launch strategy will make launch on demand a reality.

The operational community has begun to develop operational requirements and concepts for the employment of tactically responsive space assets. A fundamental question which must be answered is how long does the battlefield commander require or expect an organic space asset to survive or last in a conflict situation. The most popular answer would probably be, "as long as it is up there". There are tradeoffs which must be made regarding life expectancy, power requirements, sensing resolution, data rates, coverage, refresh period, etc. These tradeoffs will ultimately effect things such as satellite size, weight, and orbital parameters (altitude, inclination, eccentricity), and launch requirements.

The combination of requirements definition, technology advancements, and innovative launch capabilities can make small satellite systems affordable from a systems perspective.

The role of small satellite systems and multi-mission spacecraft must be well defined and orchestrated to prevent polarizing the large satellite community against small satellites. Furthermore, a coordinated architecture must be developed and agreed upon to gain funding support for small satellite systems.

Do these arguments support pursuing the development of single purpose satellites, and are these systems affordable under todays acquisition methods?

**DOD SPACE POLICY**

The United States Space Command (USSPACECOM) was established in 1985. Shortly after its creation, the other Unified and Specified Commanders and their staffs were briefed on the mission of the new command. Space Control was likened to Sea Control in the first USSPACECOM mission briefing presented worldwide in 1985. This same comparison was made by Secretary of Defense Frank C. Carlucci in his discussion of the the 1987 DoD space policy in the November/December issue of

Defense 88. Secretary Carlucci further stated in his Defense 88 article that to effectively control space we must... "Develop, operate and maintain an assured mission capability through an appropriate mix of robust satellite control, assured access to space, survivability, on-orbit sparing, proliferation, reconstitution or other means." The terms assured access to space, proliferation, and reconstitution are areas where small satellite systems can make major contributions. The national space policy released in 1988 concurs with the DoD space policy of 1987 and differentiates between civil and national security areas and commercial areas.

Just as sea control is vital to a nation's ability to pursue its economic objectives during peace and its military objectives during conflict; space control also assures a nation the ability to pursue its economic objectives in space during peace and its military objectives during conflict. The commercialization of space will take on new meaning in the next two decades as man begins to live and manufacture goods in space. The use of satellites for communications, meteorology, and warning has already become vital to our national survival. In the very near future space based navigation will become the sole means of navigation for not only the United States but for many of our allies as the Global Positioning System (GPS) becomes operational. Space based systems for detailed earth sensing and astronomy will become routine. As dependence on satellites increases, the need for assured access to space becomes critical. June 14, 1989 was a historic day, it marked the first launch of a Titan 4 launch vehicle, an event which was suppose to compensate for the loss of the Challenger three years earlier. A close examination of this launch reveals that space launch is not a common occurrence as some would have us believe. The Titan 4 was moved to the launch pad on May 15, 1988, a year prior to the actual launch. The cost of the Titan 4 launch vehicle was estimated at $220 million, the upper stage was $45 million, and the satellite launched was estimated at $187 million, bringing the total cost to almost 1/2 billion dollars. Clearly this was not a tactically responsive launch, but that is what the war fighting commanders are asking for today. They want systems which they can count upon, they do not want their requirements placed in a queue and fulfilled provided they are not out-prioritized. They want systems which are "chopped" to them in a crisis. They also want to train with the systems during exercises so they can be assured their men can operate the system.

SPACE SUPPORT TO WARFIGHTING COMMANDERS

The warfighting commanders have been using space assets for a number of years, systems such as the Defense Satellite Communications System (DSCS), FLEETSAT, and AFSATCOM have been providing communications to warfighters for years. The Defense Meteorological Satellite Program (DMSP) has been providing strategic and tactical weather data for over 15 years. Transit has provided navigation data for the majority of the maritime fleet as well as Naval vessels for over 20 years. There are other systems which provide information, although not directly, to field forces. The operational forces are becoming aware of their increasing dependence on space systems and want to participate in the design of upgrades and new systems. The USSPACECOM has begun an Assured Mission Space Support Architecture Study (AMSSAS) and have been meeting with representatives from the unified and specified commands to determine their requirements. It is expected that the AMSSAS will also dictate launch responsiveness requirements based on operational needs.

One of the common requirements I remember hearing when I visited the unified and specified commands as a representative of the newly formed USSPACECOM was that the field commanders wanted organic

space assets. They did not want to put their requirements into a queue only to be out prioritized by another user. I attempted to point out why this was not realistic since satellites provide global support and it did not make any sense to give the Commander-in-Chief Europe (CINCEUR) total control over assets which could support CINCPAC 45 minutes after the satellite left CINCEUR's AOR. The bottom line is that the CINC's want space assets "chopped" (assigned) to them during conflict in the same manner fighter wings, fleets, and armor battalions are "chopped."

Another common comment I heard when touring the unified and specified commands was "if I don't use it every day, I won't use it in combat," meaning the battlefield commanders want their personnel to operate space assets day-to-day. Familiarity with the systems upon which they rely will preclude harried reference to complicated technical orders during a crisis to understand how to use those systems. These operational personnel also want to use "their" space systems during exercises. This does not infer that tactical commanders should be given launch vehicles and a supply of satellites to be launched as they deem necessary. This topic will be further developed in the section on operational concepts.

These operational requirements can be fulfilled through the use of single-purpose inexpensive satellites which are responsive to tactical commanders.

**DEVELOPMENTS IN TECHNOLOGY**

George C. Larson states in an editorial in the June/July 1989 *Air & Space*, "The achievement of that goal (referring to the Apollo lunar program) did not create vast new technologies. To an overwhelming degree, as the stories by Kenneth F. Weaver and T.A. Heppenheimer point out, the Apollo program took what was on the shelf, then developed and refined it. There was no other way to build vehicles that would be so reliable as to approach perfection. Whole-sale inventions are almost never reliable."

If this "off the shelf" approach is used to develop small satellite systems, a great deal can be saved in research and development time and costs; additionally, more reliable systems can be produced which will lead to greater acceptance by the operational community.

Technology continues to evolve at an ever-increasing rate. Charged-Coupled Devices (CCDs) will enable the creation of sensing arrays in multi-spectral bands, Very High Speed Integrated Circuit (VHSIC), and Very Large Scale Integrated Circuit (VLSIC) will provide the capability to place a greater number of components on the chips of tomorrow. This will result in greater capabilities at reduced weight and power. As sensing capability increases, so does the space to ground data throughput. With today's technology, the transmission of large quantities of data to the ground requires broad bandwidths and high power to close the link with the ground stations; these two factors are not compatible with small satellite systems. Image compression techniques have been developed which reduce the quantity of data required to be transmitted to the ground. As satellite on-board capabilities increase, data can be processed on the satellite before transmission to the ground. This will further reduce the downlink bandwidth required and permit users to receive only that data which concerns them.

Small space-rated GPS receivers will enable a satellite to determine its ephemeris throughout its orbit. This information will be transmitted to users so they can calculate their next contact with the satellite. This will eliminate the requirement to forward satellite ephemeris to forward users. The ephemeris generated will be more accurate than what is created today through the USSPACECOM satellite tracking network since data will be gathered throughout the entire orbit instead of from fixed tracking stations located in the northern hemisphere.

DARPA has solicited proposals for Lightsat technology through a Broad Agency Announcement (BAA); The Office of Naval Research has put out a BAA for SPINSAT technology; AFSPACECOM is developing a
Statement of need for a tactical satellite system (TACSAT); the Air Force Systems Command Space System Division (SSD) is in the process of issuing a Program Research and Development Announcement (PRDA) for new, innovative, and affordable concepts and approaches to satisfy the tactical commander's dedicated intra-theater communications needs; SSD has issued a BAA for an Advanced Space Technology Program (ASTP), small satellite platforms capable of carrying a series of specific experiments into space.

Recently the Strategic Defense Initiative Office (SDIO) announced breakthroughs in the miniaturization of parts for high-technology weapons known as "Brilliant Pebbles". A research and development vehicle was flown for a short duration by scientists at the Lawrence Livermore National Laboratory. These "Brilliant Pebbles" are approximately three feet long, one foot in diameter, and weigh about 100 pounds. Smaller vehicles, weighting as little as 10 pounds, are envisioned for the future as the size of a Cray computer is reduced to the size of a deck of cards. The system of the future will employ fiber optics, charged-coupled devices in curved focal planes to provide the high resolution required to detect reentry vehicles over a wide field of view, and on-board super-computers to process the data. Operational concepts call for deployment of thousands of these small satellites. "Brilliant Pebbles" could be deployed within five years, according to the SDIO office.

The technology being developed for SDI will have spinoffs. The advanced sensor systems, computer systems, and new advances in the construction of small satellite vehicles will make other small satellite systems a reality.

The large quantities envisioned for SDI could drive the costs down to where small satellites are not only very capable but cost competitive with other means of gathering and/or distributing information.

All of the programs identified in the preceding paragraph will contribute to the development of small tactical satellite systems.

DEVELOPMENTS IN LAUNCH

Since the Challenger accident there has been renewed interest in expendable launch vehicles. The national space policy has encouraged commercialization of launch systems. One of the innovative concepts which DARPA is pursuing is Pegasus, an air launch vehicle with significant capabilities especially in the small satellites arena. Pegasus has the potential to fulfill responsive rapid launch requirements for satellites in the 400 pound range. At approximately $6 million dollars per launch, this concept is significantly cheaper than any existing launch system. (approximate costs of existing systems are: Scout: $10 million; Delta: $45 million; and Titan III: $100 million). NASA is involved in a Standard Small Launch Vehicle (SSLV) program which has the potential to lower the cost of placing satellites in orbit.

A major change is required in the method that launch vehicles are prepared and satellites integrated to the launch vehicle. The United States assembles the vast majority of its launch vehicle on the launch pad, performs checks and tests, then places the satellite on the launch vehicle and performs integration tests and satellite readiness checks. The exception to this vertical assembly is the Scout launch vehicle which is assembled and integrated with the payload horizontally than erected on the launch pad and launched. Prior to launch a system readiness test is performed on the entire system. If a problem is discovered it is fixed on the launch pad, or if the problem is significant the satellite is de-mated and the launch vehicle is taken apart until the problem is identified and fixed. The launch vehicle "stack" is then reassembled and tested again. This launch process is usually


measured in months. If a launch failure occurs, further launches are halted until the cause is identified, a fix is made, and responsible personnel are fired. Contrast this with the launch methods of the Soviet Union, who integrate their launch vehicles horizontally in facilities adjacent to the launch pad, and integrate the satellite while the launch vehicle is still horizontal. Once their checks are complete they move the launch vehicle, with the satellite attached, to the launch pad and erect the "stack" and launch within hours or days. They have demonstrated a robust launch capability by launching several satellites from the same pad in a single day. The Soviets do not operate on 100 percent expected success. They have experienced a launch failure and launched another of the same kind of satellite within days.

The Scout launch vehicle is assembled and the satellite mated in the horizontal position. The concept of horizontal integration and mating of the satellite is not new to our space business. This method has been successfully used for Scout launch vehicles for over fifteen years. Likewise, the Pegasus launch vehicle will use horizontal assembly and satellite integration.

OPERATIONAL REQUIREMENTS & CONCEPTS

The Army Space Institute at Ft Leavenworth, KS is actively integrating space into the battlefield. They are developing Army space doctrine and a manual titled "Space Support for Army Operations". This manual defines the use of space-based sensors in support of the "AirLand Battle" doctrine.9

Rear Adm. David Frost, Commander of the Naval Space Command stated to Aviation Week that the Navy views space simply as an extension of what the Navy has been doing for years, but from a higher vantage point. He further stated, "we (the Navy) have a cultural bias in that we tend to trust the things we own and control ourselves. If we don't feel we've got enough control over [space assets], or worry that they won't be there when we need them, we won't place much dependence on them as we otherwise would."10

The Air Force conducted a Blue Ribbon panel last fall which developed an implementation plan to normalize space in the Air Force. The plan covers doctrine, strategy, force structure, organization, and training. The panel recommended that the Air Force remain the principal, but not the exclusive, military space agency.11

An operational concept which is supported by the Army and Navy would place the space asset under the command of the tactical commander so he could task the asset directly. The Tracking, Telemetry, and Commanding (TT&C) as well as anomaly analysis and resolution would be the responsibility of the Air Force Space Command. A nominal constellation of satellites would be maintained in orbit to allow field commanders to use the space asset for training and during exercises. If a conflict arose the tactical commander could request additional space assets be launched to fulfill his requirement. This might involve optimizing the constellation to meet the field commander's specific requirements.

The National Academy of Sciences recently concluded in a study known as the "Navy 21" study, that space-based systems will be a key factor in 21st century sea engagements. "Future U.S. ships may carry ASATs and lightsat boosters. During a conflict, the lightsat boosters would be launched to augment or replace systems destroyed by enemy ASATs. We need to militarize our space assets, and that includes spares," a panel member stated. The Navy 21 study addresses the need for tactically responsive single purpose satellites to meet

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11. Ibid.
the future requirements of the Navy.12

AFFORDABILITY

Small satellite systems will not become a reality unless the total system costs can be reduced to a level where the tactical forces can use the systems on a day to day basis for training, and commanders can request launches in support of exercises to develop familiarity with the systems in accordance with new tactics and doctrine. There are several methods of reducing costs, however changes in development, acquisition, and launch philosophy are required.

In a May 2, 1989 letter from Mr. Bob Davis, president of EPRIME AEROSPACE CORPORATION, to the Honorable Bill Nelson, Chairman of the House Subcommittee on Space Science and Application regarding NASA's Request for Proposal (RFP) for the Medium Expendable Launch Vehicle (MELV), Mr. Davis states that it will cost approximately $1.25 million for the combined effort of EPRIME and all their subcontractors to fully respond to the MELV RFP as it is currently written. Mr. Davis further states that if EPRIME treated the RFP like any other commercial procurement for a fixed price contract, it would cost less than $100,000 to give the technical and price proposals and an implementation plan including schedule and launch assurance plans13.

NASA's approach to doing "business as usual" was criticized by Representative Bill Nelson in a May 3, 1989 letter to Mr. Dale D. Meyers, Acting NASA Administrator. In the letter Representative Nelson encourages NASA to unburden industry where possible by departing from some of its traditional procurement methods in areas where the Federal Acquisition Regulations authorize. Examples cited were cost controls and accounting procedures which are not compatible with a fixed price contract. The letter concludes with the following statement: "I will not approve the agency's (NASA) plans to proceed with the small launch vehicle procurement without a clear demonstration of effort to develop a commercially reasonable approach. That procurement should reflect radical changes from the MELV RFP"!4.

The National Space Policy of 1988 directs emphasis be placed on the commercialization of space. The development of space-based sensing systems are identified in a National Security Decision Directive. This commercialization will enhance the United States' ability to maintain its place among world space powers. It will also enhance competition for launch services and spacecraft development which will result in reduced costs. Reduced launch and satellite development costs are required to make small satellite systems a reality within the next decade.

A recent decision by the Navy to test commercial computer technology in critical military programs has led Unisys Corp. to consider selling its $2 billion defense business. According to the May 29, 1989 issue of Defense News, other diversified companies are getting rid of their defense operations, because of decreasing defense budgets and the bureaucracy which must be accommodated when doing business with the government15. As stated earlier the cost of meeting military standards can add up to ten times the cost of doing business. Accepting commercial off the shelf (COTS) materials and best commercial practices for testing can greatly reduce the cost of space systems.

It is important to understand where MIL standards originated and why they exist. The early days of the U.S. space program


were marked with numerous failures, launch failures, failure to achieve desired orbit, satellite infant mortality, power system failures, attitude control failures, satellite computer failures, and numerous others. In an attempt to eliminate these failures stringent standards were developed which were intended minimize the occurrence of previous failures. When new failures occurred new standards were developed to preclude a reoccurrence. I have not known of a single standard which has been deleted. It is not unusual for proposals for space systems to be several volumes and weigh several hundred pounds. The technical volume for the space system may be page limited, but the required documentation for cost and other areas easily fill hundreds of pages. In a recent article about the Wallops Island Space Flight Facility, Larry J. Early the chief of the projects division stated that documentation for launch is virtually zero at Wallops Island. This increases the level of risk, however NASA is willing to accept the risk because the launches are unmanned and to minimize the chance of failure through extensive testing and evaluation would be very expensive. The approach is to fly more missions instead of flying fail-safe. This same approach could be used to decrease the cost of small satellite systems.

RELATIONSHIP BETWEEN SMALL SATELLITES and MULTI-MISSION SYSTEMS

There are large multi-mission satellite systems which exist today that could provide the tactical commander the data he requires to effectively and efficiently deploy his forces to counter an adversary. These systems are not dedicated to the tactical commander, and while he may request support from them, his request is placed in a queue along with other requirements. The tactical commander usually does not have a high enough priority to successfully compete with other organizations and agencies, thus his requirement go unfulfilled. There is nothing wrong with this system. Multi-mission systems have been developed to meet a broad range of requirements from differing organizations. The high cost of launching space systems has contributed to the philosophy of getting the most for launch dollars, this has translated to placing more sensors on satellite platforms, increasing the utility of the systems by performing multiple missions which satisfy the requirements of many different users. This "fly one, satisfy all" approach is satisfactory provided the users are not dependent upon time sensitive information. For information to be of value to the tactical commander, it must be received in time to effect the deployment and employment of the commanders forces in a dynamic battle environment. In many cases this would be in near real time. If the tactical commanders cannot depend on the availability of data from multi-mission satellite systems, they will not use these systems during conflict to achieve the force multiplier effects possible, nor will they employ the doctrine and tactics developed around space based support systems. Tactically responsive satellite systems which appear to the tactical commander as organic resources are possible using small single purpose satellites, and new responsive inexpensive launch systems.

These small tactical satellite systems would fulfill the requirement of the tactical commander for a responsive, organic, reliable space asset. They would not be in competition with multi-mission systems. The tactical single purpose small satellite system could fulfill multi-mission satellite shortfalls resulting from on-orbit failures. Therefore, the two systems should be viewed as complementary systems, not competitive, each fulfilling specific requirements and providing a symbiotic relationship.

SINGLE-PURPOSE SATELLITES

The vast majority of satellites in orbit today are multi-purpose. As a result these satellites tend to be large and expensive and require large expensive launch vehicles which take several months to prepare for launch. The concept of a single purpose satellite assumes that technology exists

which would enable the mission to be performed by a small satellite. If the satellite is small the launch vehicle could be small. Thus the cost of the overall system would be lower than current systems. Potential missions which could be accomplished by small satellite systems would be: communications; surveillance (imaging and electronic); meteorological; and store and forward missions involving remote sensors. As new technology evolves so will additional missions.

COST REDUCTION

A philosophical change is required in the method we acquire our space systems. The first thing which must be accomplished is to analyze the requirements for the system: How long must it operate? How many are required (block buys can save substantial amounts on the system buy)? What response requirements have been identified? Is a launch system available, or will one have to be designed and procured?

How do we build small satellites cheaply? Highly complex electronic equipment is being developed and produced today. This equipment is highly reliable, due in many cases to redundancy of high failure items. In the computer industry this progress in technology is evident. At the beginning of 1989 Apple offered memory upgrades for Macintosh SE computers at a cost of $1200 per megabyte. In May, 1989, one megabyte upgrades could be purchased for $181.00. In June 1989, the cost of one megabyte upgrades dropped to $131. By the end of 1989 the cost is expected to drop to $100.00 or less. These computer memory chips come with a lifetime warrantee. This simple example of the rate of evolution in technology enhancements available today only touches the surface. New materials with exciting properties are being developed every day and have the potential to perform far beyond one's imagination.

Even though technology breakthroughs will continue to occur and provide greater capabilities, getting this technology into today's defense or space systems is not an easy task. Much of the technology is developed for application outside the space arena. Therefore, it is not space rated nor does it meet MIL STDS or MIL SPECS. Hardware which falls in this category is referred to as Commercial-Off-The-Shelf (COTS). If COTS hardware were used to build the tactical satellites described earlier in this paper the cost could be reduced by at least 10 times. This reduction in cost would result from: 1) not having to maintain a library of all applicable MIL STDS; 2) not having to test all materials and parts in accordance with the appropriate MIL STD; 3) procuring material commercially; and 4) developing alternatives to space rating requirements.

Are volumes of MIL STDS required to build small single purpose satellites? If the answer is yes, they will probably not be inexpensive. To answer this, one must look at how and why MIL STDS were created. The early days of the space program were punctuated by numerous failures. These ranged from launch failures to hard satellite failures. When failures occurred, investigations were conducted to determine their causes. In order to preclude a reoccurrence of these failures, standards were developed which tended to be applied to all space programs. These standards continued to grow in number and add to the large volume of paperwork involved in producing a space system. In an article on the Scout launch vehicle Paul Goozh describes the problems encountered in the early days of the Scout. He states that after all the lessons were learned, standard operating procedures filled "seven fat volumes." He further states that after 25 years the procedures are virtually the same.

Despite the "seven fat volumes" of standard operating procedures, the Scout is an excellent example of the application of off-the-shelf technology and hardware being combined to produce a system; the first stage was taken from the the Navy's Polaris missile; the second stage Castor was a derivative of the of the Army's Sergeant; the third and fourth stages were versions of the Navy's Vanguard. By using existing technology and hardware, both time and
money were saved in developing the Scout.17

Likewise, in the future, using streamlined launch and integration procedures, and employing COTS technology, space assets which are timely, more responsive to operational exigencies, and cost-effective are within reach.

ABOUT THE AUTHOR

Mr. Warren Watkins retired from the Air Force in December 1987 after almost 26 years of service. He has been involved in satellite operations for over seventeen years. He started his satellite operations experience in 1972 when he was assigned from a Titan II missile crew to the 4000th Aerospace Applications Group (AAG) to command and control Defense Meteorological Satellite Program (DMSP) satellites. While at the 4000AAG Mr. Watkins served as a satellite systems controller, chief, standardization and evaluation branch, chief, training branch, and operations director for the recovery of two spinning satellites (at the time, this type of recovery had never been completed). Mr. Watkins has extensive experience in NAVSTAR Global Positioning System (GPS) program. While at the Naval Postgraduate School he wrote a thesis on the Operational Requirements and Organizational Structure Required to Support the Global Positioning System. While assigned to the 1st Strategic Aerospace Division at Vandenberg Air Force Base, CA, he developed the organizational structure for the GPS command and control facility which is in being at the Consolidated Space Operations Center (CSOC), Falcon Air Force Base, CO. Mr. Watkins also served in the Air Force Space Command (AFSPACECOM) plans directorate as the Command's program element monitor for the DMSP and GPS programs and later as chief, long range plans branch. He was selected as a member of the initial cadre for the United States Space Command (USSPACECOM) when it was formed in 1985. In this capacity he served as chief, space support division.

Among his accomplishments, Mr Watkins was a member of the Space System Architecture 2000 study, which identified space requirements through the year 2000, he was the AFSPACECOM representative to the Aerospace Forum which provided a vision of the Air Force major commands in the year 2005, with space fully integrated across all mission areas. He developed the concept for a GPS users conference and chaired the first three meetings. He organized and chaired the first GPS command and control working group. While assigned to the USSPACECOM he developed the concept for a command master plan which would show the relationships between the many programs of the future that would be assigned to CINCSPACE. The master plan has been developed and provides an insightful view of the future. As an employee of SRS Technologies, he was a key player in the development of the USSPACECOM phase I BMD Concept of Operations.

As an employee of CTA INCORPORATED, he played a key role in the development of a Tactical Imaging Demonstration and Experimentation System, a small satellite with significant utility to tactical commanders.

Mr. Watkins holds a BS in Mathematics from the University of Tampa, and a MS from the Naval Postgraduate School in Systems Technology, specializing in Command Control and Communications.