The Role of Small Satellites in Our National Defense

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ABSTRACT

Highly capable small satellites may play a significant role in the future of our national defense space architecture. Such capable small satellites are generically referred to as "LightSats." In this paper, we examine the logical motivation behind the utilization of LightSats to support military operations and national defense requirements. To complement LightSats, new cost-effective and responsive launch vehicles are also needed. We present an overview of the DARPA Advanced Space Technology Program (ASTP), which seeks to develop high-payoff advanced enabling technologies to enhance space system operational support to military forces and to assure availability of space assets in wartime. The program is comprehensively addressing all of the key segments of an assured access to space capability, including initiatives in launch vehicles, satellites and their subsystems, ground systems and novel operational concepts. The technologies developed under ASTP auspices will improve large defense satellites by decreasing the size and weight of their subsystems, and perhaps enhancing their capabilities and survivability. Additionally, these technological advances may make possible the advent of high capability LightSats.

The work being done in DARPA for the defense community synergistically complements similar small satellite and launch vehicle efforts in the commercial and scientific communities. ASTP is helping to "prime the pump" of our nation's emerging commercial space industry, and the ramifications of this program may be far more widespread and diverse than the directly discernable impact on military space systems. For example, ASTP efforts to streamline manufacturing processes and thereby reduce the cost of inherently expensive space systems will be beneficial to the commercial and scientific space communities in addition to the defense establishment. In this regard, ASTP contributes to maintaining and invigorating our nations technical leadership in space.

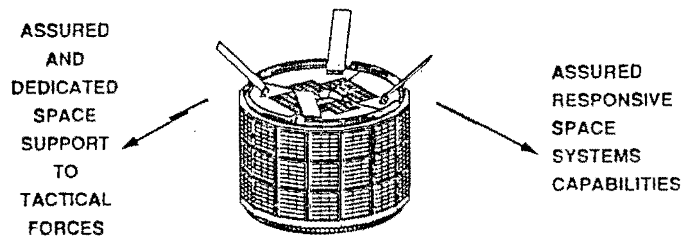
In addition to discussing the ASTP initiatives in some detail, we also present an overview of representative technologies and concepts for near-term (3-10 years) future LightSats which may offer significant military utility at cost-effective prices. In the Addendum to this paper, we also take a speculative look at potential areas of cross-fertilization between defense, commercial, and scientific LightSat developments for the far-term future (10-20 years).

INTRODUCTION

The vital importance of assuring availability of space assets in wartime has received a great deal of attention in recent years. A 1988 Defense Science Board (DSB) Summer Study highlighted the growing concern that we must assure the availability of space assets in time of war.

There are two critical components to this issue of assuring military space mission capability. First, there is a military need for responsive space capabilities, which may include timely launch capability as well as the ability to augment and reconstitute our backbone space systems. The second component is a military need to provide space systems which are dedicated to support tactical commanders. One possible solution that can synergistically satisfy both facets of this assured space mission capability goal is to reduce the size and cost of satellites and their launch vehicles. Indeed, the Congress of the United States has been greatly interested in reducing space system costs while nevertheless meeting our defense needs.

ASSURED ACCESS TO SPACE



LightSats have the "right stuff" to synergistically satisfy national requirements for responsive space capabilities, and tactical commanders requirements for assured and dedicated space systems support.

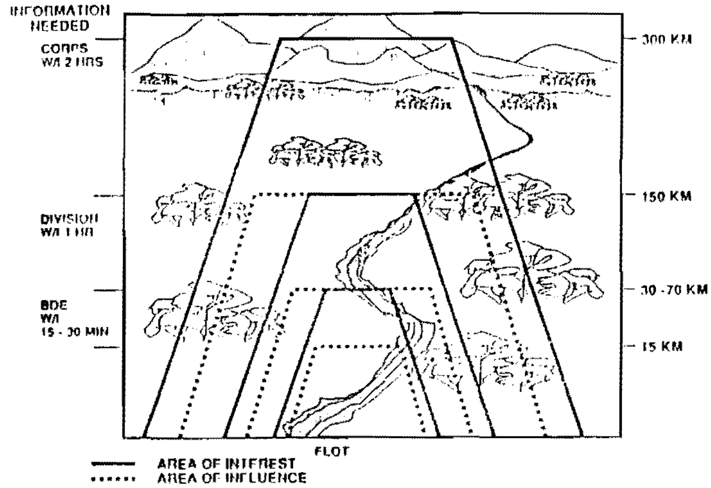
The Advanced Space Technology Program (ASTP) established by the Defense Advanced Research Projects Agency (DARPA) is addressing these issues. The central guiding objective of the Advanced Space Technology Program is to define, develop, and demonstrate high-payoff advanced technologies to enhance space system operational support to military commanders and to assure availability of space assets in wartime. Additionally, ASTP technologies will contribute to the enhancement of future major satellite systems, which are often necessarily large and complex, by reducing the size and weight of their subsystems.

Our program in DARPA is designed to comprehensively address all of the key segments of an assured space mission capability, including launch vehicles, spacecraft, ground systems, and operational concepts within the framework of an overall space architecture.

THE LOGICAL IMPERATIVES FOR LIGHTSAT

A key point behind the significance of the ASTP to the military is that space systems are becoming progressively more and more important as components of an optimized mix of operationally efficient and cost-effective battlefield systems.

Space offers a number of unique advantages over terrestrially based systems, including the ability to traverse international and terrain boundaries, to provide coverage and support over very large geographic areas, and to perform over-the-horizon sensing and non-line-of-sight communications.



Dedicated space systems can support military commanders over the timescales and distances which are required for tactical operations, indicated on the above schematic of the Airland Battlefield.

Space assets can support military operations across all levels of war and across the full spectrum of conflict. Since they may be considered to be "always deployed," on-orbit assets provide support from the beginnings of tensions, through crisis and subsequent invasion, to full-scale operations.

"High ground" space assets can support the tactical commander without logistically and administratively burdening him. Tactical commanders do not want to be burdened with monitoring satellite "house-keeping" functions and system status; rather, they want responsive support from space, which means operational control to task satellites as their own assets, and direct and timely access to data from space systems. This is not to say that space systems are a panacea for all defense deficiencies and requirements, but space will play a progressively more important role in the future of warfare on land, on the sea, and in the air. In addition, transfer of technologies developed under ASTP auspices may enhance other non-space related military systems.

The Advanced Space Technology Program is directed toward two compatible technology drives. First, advanced technologies can make our nation's major "capital asset" satellites more capable and perhaps more cost effective and survivable. And secondly, high technology can herald a new class of cost effective, small satellites that could be devoted to supporting tactical commanders.

This new class of satellites is generically referred to as LightSat. There is a great deal of synergy between these two goals, and the Services can benefit from both, although tactical users are probably more interested in the latter. It is important to emphasize that LightSats would not compete with large sophisticated satellites which perform vital defense functions and missions. Quite the contrary, LightSats would complement our major satellites by expanding coverage in space and time, by permitting more space system users, and by facilitating direct user tasking ability and interaction with a satellite as well as more timely distribution of data from space.

LightSats will not have the power and sophisticated capabilities of large spacecraft, but we believe that the capabilities which advanced technologies can make possible will yield cost-effective small satellites that, nonetheless, offer significant military utility.

At this point, it is important to clearly define the term LightSat. Our earliest satellites, by mere weight definition, could be called "LightSats." There is a key distinction between these earlier lightweight satellites and the efforts being undertaken in the ASTP.

To be cost-effective and to have a significant role in advancing the prospect of assured access to space, tomorrow's LightSats must be significantly more capable than systems based on current state-of-the-art technologies. Thus, the ASTP focus is to develop the enabling technologies upon which tomorrow's high-capability LightSats will be based.

What might we expect from future high-tech satellites? Responsiveness is a key fundamental characteristic desired from a high-technology satellite architecture. By responsiveness, we mean the ability to augment present space assets during times of crisis, the ability to surge at the outbreak of a major conflict, and the ability to reconstitute space systems that have been damaged or destroyed.

Crisis augmentation requires us to expand geographic and temporal coverage of our existing space assets. During crises in which the United States is not directly involved but has an interest, augmented capabilities could play an important role. In a low-level conflict or crisis involving the United States, space assets would play a vital role and the capability to augment existing systems could be decisive.

Surge capability enables us to rapidly enhance existing space systems at the outbreak of major hostilities involving the United States. The ability to surge facilitates assured space mission capabilities for operational forces that would be denied, or at best have limited access, to existing space systems during a major war.

Surge capability also provides a measure of survivability via proliferation for space assets that will certainly be threatened by the ASATs of our adversaries.

And finally, reconstitution would enable us to replenish critical space systems after these assets have "died" of natural causes, or have been damaged or destroyed by direct ascent or co-orbital ASATs, by terrestrial or space-based directed-energy weapons, or by tactical use of a nuclear weapon in space.

No system, however robust, is fully indestructible. Responsive space capability for contingency operations will prevent the dire consequences of an assumed "Maginot Line" in space.

In addition to a vehicle amenable to a rapid launch sequence, timely responsiveness requires a ready-to-launch inventory or on-orbit inventory of satellites. This is precisely where cost-effective small satellites can be useful. LightSats could be launched quickly.

Large, elaborate spacecraft have procurement and launch costs that may be far too expensive for them to be utilized as ready-to-launch spares. The United States could maintain an inventory of on-orbit spares; however, these satellites would still be vulnerable and their critical systems would degrade day-by-day due to the harsh space environment.

Notwithstanding their suitability to be kept as inventory for reconstitution missions, small capable satellites should not be simply mothballed awaiting a time of crisis. Rather, they can be exploited to provide dedicated space support to tactical forces. In fact, to be truly useful in time of war, LightSats must be incorporated into peacetime training.

Capable, militarily useful LightSats may be sufficiently affordable to enable their dedicated commitment to support requirements of tactical commanders. Indeed, if LightSats could be proliferated to a reasonable degree, they would add a measure of robustness and survivability to our overall space architecture.

In a sentence, the logical imperative for small satellites is that cost-effective LightSats can, simultaneously and synergistically, satisfy evolving national requirements for rapidly responsive augmentation and reconstitution of space systems, and military requirements for assured access to space capabilities in support of their operational forces.

The general approach which the DARPA ASTP is pursuing is designed to foster manufacturing innovations and streamlined acquisition. These are important aspects of the program aimed at reducing the cost of inherently expensive space systems.

Initiatives being taken within the program include high-tech satellite applications at system level and below, and demonstrating these technologies, as well as demonstrating the novel air launched vehicle, and breaking ground on a new Standard Small Launch Vehicle.

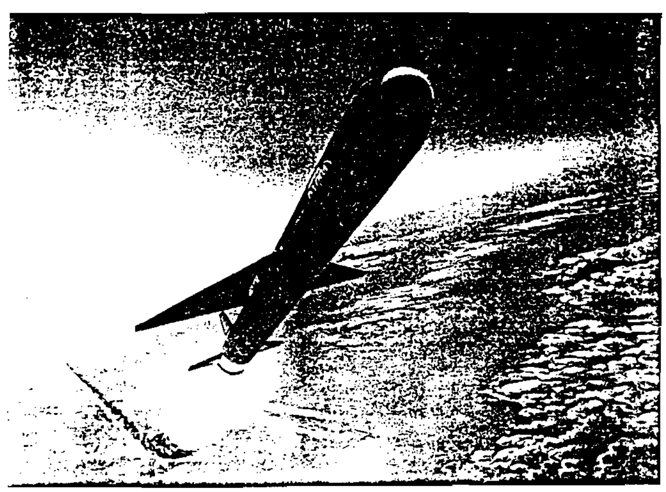
LAUNCH VEHICLE INITIATIVES

The launch vehicle segment of our program is aimed at responsive, relatively low-cost launch capabilities for small satellites. The Pegasus air-launched vehicle (or ALV) and the ground-launched Standard Small Launch Vehicle (or SSLV) are initiatives being funded and supported by DARPA.

The logical motivations behind the ALV and SSLV include vulnerability of our presently limited national launch facilities, and the need for a launch vehicle to complement LightSats. The United States is presently tied to a limited number of launch sites which would presumably be targeted in a major war. In addition, these sites are vulnerable to natural disasters or sabotage. A transportable SSLV and a mobile ALV facilitate assured access to space by offering the potential for assured launch capability.

The ALV and the SSLV complement the development and deployment of small satellites for responsive space capabilities and for support of tactical forces. A LightSat effort may run aground without a cost-effective launcher. Conversely, development of an SSLV or ALV without simultaneous development of the appropriate payload class would be pointless. The ALV and SSLV, with LightSat payloads, are the systems which could have the "right stuff" to provide our nation with a responsive space capability in the future.

Finally, efficient, responsive, and cost-effective launch vehicles could reduce the cost of putting satellites into space and thereby make space systems more affordable. More widespread utilization of space capabilities might then be expected to follow.



The Pegasus Air Launched Space Booster in Lifting Ascent to Orbit

The Pegasus Air Launch Vehicle is a winged rocket that is dropped from a carrier aircraft. The vehicle is being developed by Orbital Sciences Corporation and Hercules.

The characteristics of the ALV have several advantages over terrestrial launch vehicles. The payload capacity is enhanced because of a number of physical and technical factors. These include the momentum provided by the carrier aircraft, the aerodynamic lift provided by the winged stage, reduced atmospheric drag and gravity losses, and the ability to maximize engine performance for high-altitude operation.

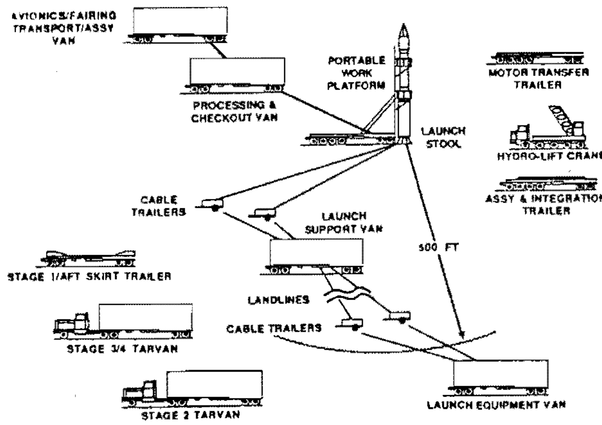
The ALV will meet the low throw-weight end of our launch requirements and will provide a rapid-response capability for national defense missions. It offers flexibility in terms of optimizing the payload's initial ground track coverage over desired geographical regions of interest, which is an important attribute for crisis responsiveness. The air launch vehicle could afford survivability via mobility and proliferation.

The ALV missions will utilize the same NASA B-52 that deployed the old X-15. Pegasus will be dropped at an altitude of 40,000 feet. The first stage will then ignite and the vehicle will hypersonically climb to over 200,000 feet. The first stage will be jettisoned and the remaining two stages will continue the flight in the more traditional launch vehicle fashion.

Pegasus may also serve as the replacement vehicle for the SCOUT, which is presently being phased out from our expendable launch vehicle (ELV) fleet. The SCOUT rocket has been our nation's workhorse for launching small payloads for the past two decades.

The initial flight of the ALV will accomplish several goals in addition to the primary objective of a first-time proof-of-principle demonstration. The first stage of Pegasus will be instrumented to obtain hypersonic flight data. The data will be utilized to evaluate the vehicle's performance and to validate the computational fluid dynamics (CFD) codes which were used in the design of this vehicle. This validation is especially important to the developers of the National Aerospace Plane. The aerodynamic performance of Pegasus during its hypersonic flight has only been studied with computer simulations, since wind tunnels do not operate above roughly Mach 7. This is another exciting and challenging aspect of the Pegasus program. An additional significant accomplishment of the ALV program is the demonstration that private industry, in a unique partnership with the government, can design, fabricate, and provide a vehicle for launch within a two-year period.

The payload for the first mission will consist of a small Navy communications satellite and a NASA-built satellite called "PEGSAT." Barium gas will be released while PEGSAT orbits over the north polar region at an altitude of 320 nautical miles (NM). Ground-based observations of the dispersing gas cloud will facilitate geomagnetic field line mapping as well as measurements of other electromagnetic and plasma properties.



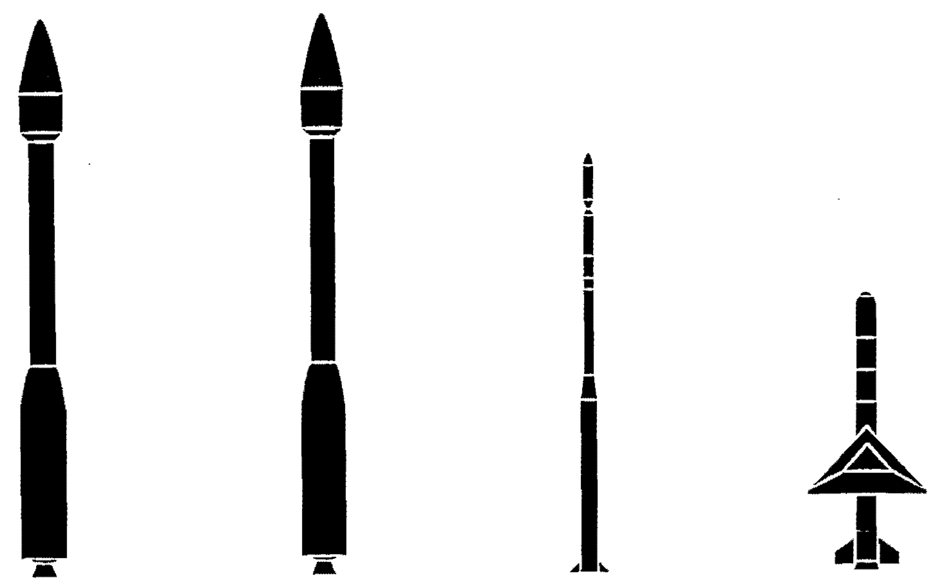
The Standard Small Launch Vehicle is supported by a transportable launch complex.

The Standard Small Launch Vehicle, or SSLV, is intended to be a transportable, ground-launched rocket with the ability to be rapidly deployed. Our goal is a 72-hour response time from alert to launch. The SSLV will be developed to satisfy payload requirements between the Pegasus and Delta class vehicles. This will demonstrate the capability to rapidly launch multiple LightSat payloads into low earth orbit or single LightSats to higher altitudes such as 4, 6, 8, or 12 hour Molniya orbits. (Molniya orbits are stable, highly elliptical orbits which can maximize a spacecraft's time over a particular theater of operations.)

The SSLV will be capable of placing a 1000 lb payload into 400 NM polar orbit. Smaller satellites could be launched together to make up the available lift capability, or a satellite weighing less than 1000 lb could be launched into a higher altitude orbit.

A DARPA contract with Space Data Corporation was recently signed for an initial SSLV flight, at a cost under $10 million. The proposed SSLV, named TAURUS, uses a modified Pegasus vehicle atop a Peacekeeper first stage. It may be possible to enhance the vehicle's performance by stiffening the upper stages to withstand the accelerations which can be produced by the first stage. (The initial SSLV will ballast the first stage to prevent overloading the upper stage structures.)

The ASTP is pursuing a very challenging near-term launch schedule involving three separate launches over the next six months. Eleven individual satellites will be deployed on these three missions. In addition to PEGSAT, which will be deployed on the first Pegasus launch, two types of communications LightSats will be launched using the SCOUT rocket and a second Pegasus flight.



	ENHANCED SSLV	SSLV	SCOUT	ALV (PEGASUS)
GROSS WT	180,000 LBS	180,000 LBS	48,000 LBS	42,000 LBS
PAYLOAD *	2300 LBS	1,000 LBS	322 LBS	400 LBS
LV COST ($M)	$15.0	$15.0 - 12.0	$12.0 - 15.0	$6.0
$/LB	$6,522	$15,000 - 12,000	$37,267 - 46,584	$15,000

* 400 NM CIRCULAR POLAR ORBIT

Comparison of Launch Vehicles

SPACE SEGMENT

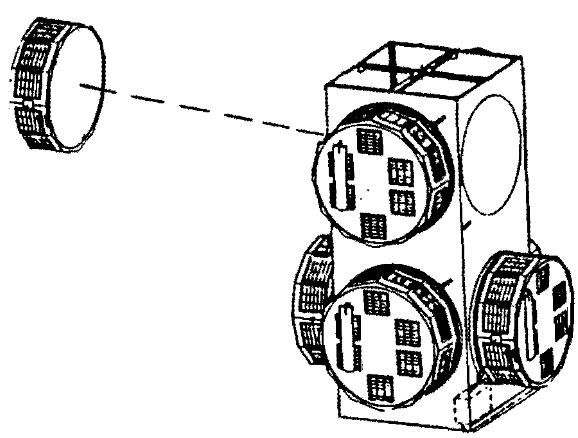
The space segment portion of the Advanced Space Technology Program has both a near-term and a far-term perspective. In the near-term, two store-and-forward communications satellites called MACSATs and seven "bent-pipe" relay satellites called MICROSATs will be fabricated and launched. (A store-and-forward system involves storage of an uplinked message in the satellite's memory and, subsequently, downlinking that message to the intended recipient anywhere else on earth, when the satellite passes over that recipient's location.)

These spacecraft will demonstrate available technology harnessed in satellites dedicated to operational forces, and they will be exercised by the Services as part of the ASTP demonstration program.

The far-term focus of the ASTP is to elucidate and develop advanced enabling technologies and concepts of operations. This element of the program will be discussed below, following an overview of the initial near-term LightSat demonstration program

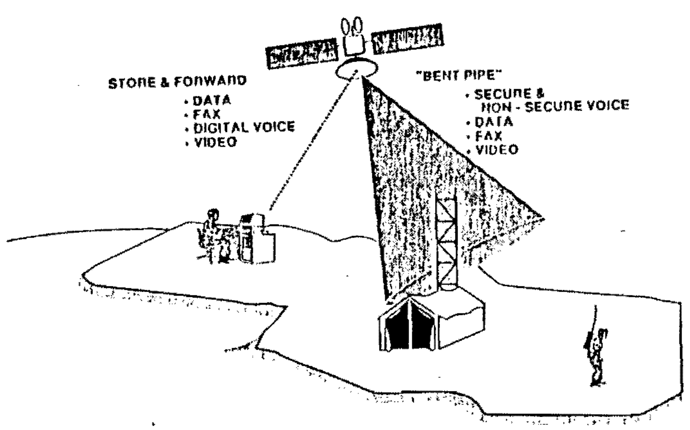
INITIAL DEMONSTRATION PROGRAM

The primary goals of the ASTP demo program will be to demonstrate measurable benefits derived from an assured space mission capability for tactical forces, and to interact with the user community in establishing conceptual foundations and requirements for future systems in communications as well as other application areas. It is important to emphasize that LightSat systems are certainly not limited only to communications; rather, applications in the areas of tactical surveillance and targeting, meteorological and terrain sensing, position-navigation systems, and others are being pursued as potential candidates for future LightSat demonstrations.



MICROSATs being deployed from their bus atop the Pegasus third stage

The initial demonstrations will involve two types of UHF communications satellites currently being fabricated by Defense Systems, Inc. At an orbital altitude of 400 NM these communications satellites will provide coverage over wide geographic areas. Most of the European Theater of military operations, including Northern Africa and the Middle East, can be covered by a single satellite's instantaneous footprint.

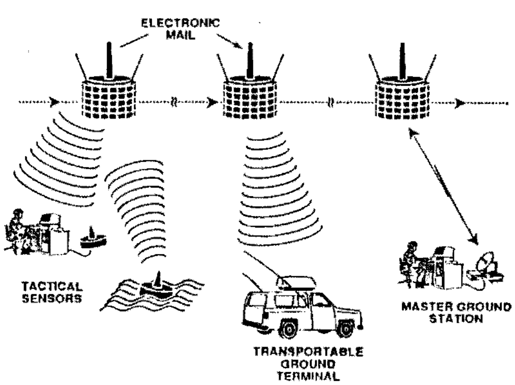


MICROSAT Mission Concepts

MICROSAT is so named because of its relatively small size and weight, which is less than 50 pounds. A constellation of seven coplaner MICROSATs will be launched by Pegasus. MICROSAT will provide a "bent-pipe" relay capability for voice, data, and facsimile transmissions, as well as slow-speed transmission of video frames or computer displays.

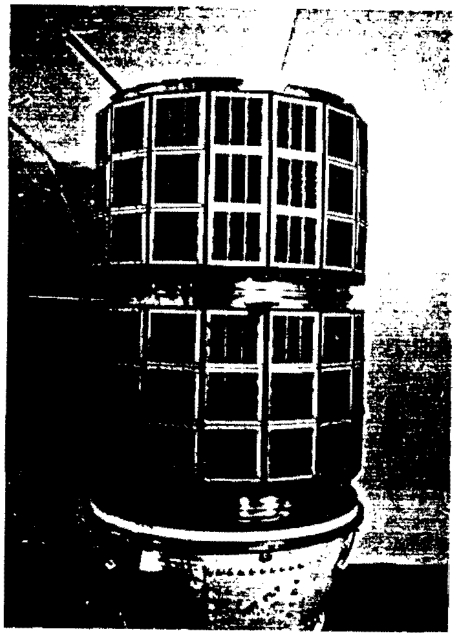
High-fidelity secure voice and encrypted data can be used with MICROSAT, which will also have a limited store-and-forward capability.

MACSAT, or multiple access communications satellite, offers an "electronic mailbox" data store-and-forward capability. This satellite will facilitate worldwide database transfer and message relay as well as data collection from sensors.



MACSAT Mission Concept

Two MACSATs will be launched into a 400 NM polar orbit aboard a SCOUT launch vehicle. Each 150 lb MACSAT will operate with manned ground stations and with unattended sensors.



MACSATs undergoing a fit check for the SCOUT launch vehicle

Significant technical efforts have been undertaken to ensure interoperability of our LightSats with existing military ground segment equipment. It is vital that a LightSat system, designed to be relatively inexpensive, be interoperable with existing or planned ground systems. The cost savings of a LightSat would be offset if a new set of ground equipment had to be procured. Also, operational issues such as scheduling, logistics,and operator training are being addressed in support of the initial demonstrations.

LightSat systems are intended to employ simplified satellite control functions and to rely on satellite autonomy to reduce the level of required ground control. Our initial demonstration system takes a step forward in this direction. The system will be commanded and controlled by a PC-based Master Control Station, which can be operated by tactical commanders to directly control satellite functions and scheduling.

In addition to developing and demonstrating the enabling technologies that can make possible high-capability LightSats, key conceptual issues that underlie viable LightSat architectures must be addressed before such systems would be considered for military procurement. The fundamental questions that must be addressed include:

1. What are the appropriate mission areas and technology applications to be incorporated into small satellite systems supporting operational commanders?

2. Can LightSats perform missions to enhance present operational capabilities?

3. Can these satellites satisfy presently unsolved requirements or needs?

4. Do LightSats offer a unique solution to some requirements?

5. What are the fundamental system specifications required for militarily useful LightSat capability; for example, what would be the minimum number of small communications satellites placed in low earth orbit to achieve a desired operational capability?

6. What are the true life-cycle costs associated with a LightSat system, to include the costs of the required number of satellites themselves, associated launch costs, ground segment personnel, and operations costs?

CAPABILITY	ABILITY TO MEET SPECIFIC NEEDS OF OPERATIONAL COMMANDERS
AVAILABILITY	ACCESSIBILITY FOR USE BY SPECIFIC OPERATIONAL COMMANDERS
RELIABILITY	CONFIDENCE OF OPERATIONAL COMMANDERS IN SUPPORT
ENDURABILITY	ABILITY TO WITHSTAND ENVIRONMENTAL STRESSES, DEGREE OF QUALITY, AND LENGTH OF OPERATIONAL/ON-ORBIT LIFE
VULNERABILITY	SUSCEPTIBILITY TO ATTACK
SURVIVABILITY	CONTINUED ABILITY TO PROVIDE NEEDED COVERAGE DESPITE ENEMY ATTACKS
SUSTAINABILITY	ABILITY TO PROVIDE NEEDED COVERAGE DESPITE FAILURES IN LAUNCH OR ON-ORBIT ASSETS
BOTTOM LINE	AFFORDABILITY - DOLLARS, RESOURCES, IMPACT ON OTHER MILITARY SYSTEMS SUPPORT

LIGHTSAT ISSUES

Our initial demonstrations will assist in answering these fundamental issues. All of the Services are expected to participate in the DARPA demonstration program, and demonstrations will be conducted worldwide, on a theater-by-theater basis. The fundamental goals of the initial communications demonstration program will be to demonstrate a quick-reaction space capability for operational forces, to gain insights into operational constraints, to elucidate operational utility, and to establish baseline parameters for future small satellite systems. A detailed performance assessment of this initial LightSat system will be conducted as part of the DARPA demonstration. Measures of success include assessments of utility, performance, and effectiveness. Interactions with the user community have been ongoing to refine demonstration concepts and to perform detailed planning and coordination.

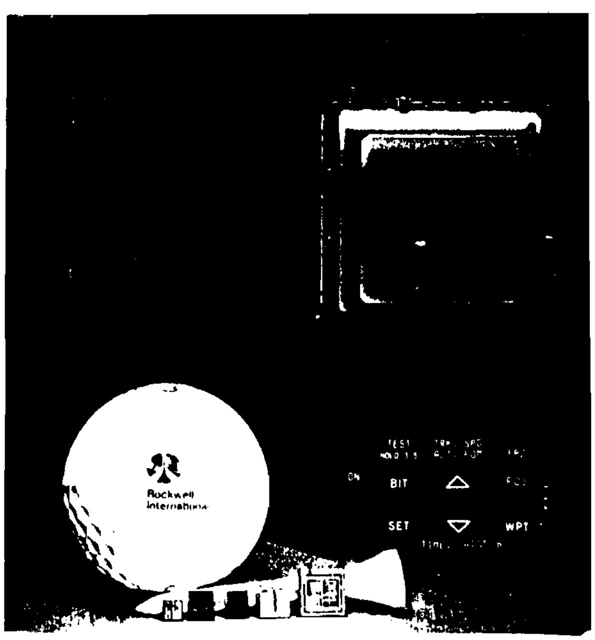
Representative demonstration concepts include store-and-forward information updates to and from CONUS forces deploying overseas; trans-Arctic and trans-Pacific UHF communications; supporting communications among widely dispersed headquarters; communications between long range surveillance units and their parent commands; and facilitating non-line-of-sight quick fire nets.

POTENTIAL LIGHTSAT SYSTEMS OF THE FUTURE

The future course of the ASTP Space segment will be determined in large measure by evaluation and selection of industry responses to a DARPA Broad Agency Announcement, which called for concepts and ideas related to satellite systems, subsystems, and components. DARPA convened a technical advisory panel consisting of Service representatives to aid in selecting the best technical proposals that satisfy Service requirements, needs, and the goals of the DARPA program.

To illustrate potential capabilities that ASTP technology developments may enable in the future, some notional system concepts will be described. Whether such systems are actually procured depends not only on the necessary technological successes but also on the determination of significant military utility, cost-effectiveness, and overall return on investment.

A multi-channel EHF LightSat, which would be compatible with more capable MILSTAR satellites, would offer the Anti-Jam (AJ) and Low Probability of Intercept (LPI) advantages of EHF communications. MILSTAR compatibility implies that this LightSat would not need a new set of ground equipment, and in fact these LightSats could be used to augment or partially reconstitute a MILSTAR constellation. (These small MILSTAR compatible LightSats might be appropriately named "MILISTARs.")



Micro-miniaturized GPS receiver developed under DARPA sponsorship

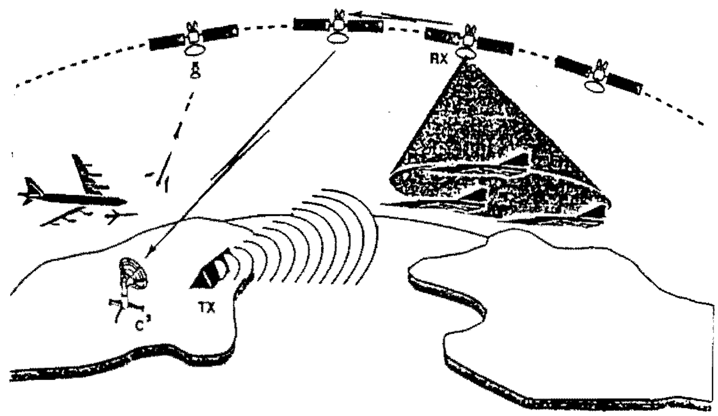
Previous DARPA advances in micro-miniaturization have resulted in a miniature GPS receiver (the size of a cigarette pack) that certainly has application for space systems, whether on traditional large or small satellites.

Further development and application of these types of technologies could provide autonomous navigation and attitude control systems. Autonomous satellites require less "housekeeping" attention, but would nevertheless be responsive to operational control from tactical commanders.

Advances in visible and IR optics will enhance surveillance and target acquisition capabilities to support tactical operations from space. For example, binary optics is a technology relying on advanced optical theory to produce low weight optical elements with greater manufacturing ease and lower costs than ever before. Thus, a high quality optical system might someday be packaged as a relatively low cost LightSat. Of course, such advances in optics technology, reducing weight and cost, also has direct applicability in battlefield systems used by the services.

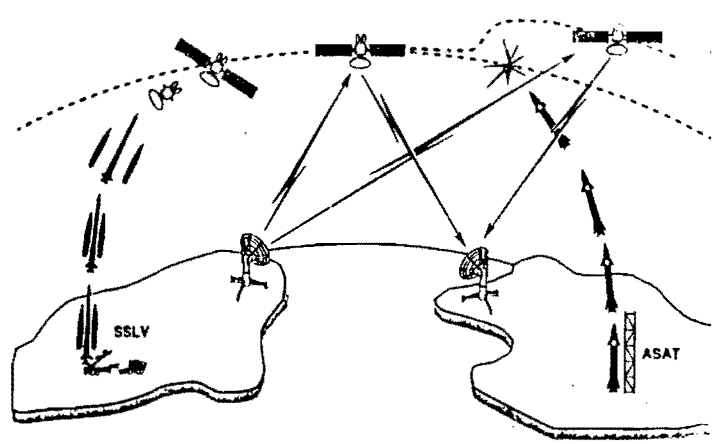
Advances in microelectronics, microwave integrated circuits, advanced computer processors, data compression technologies, and integrated optics could provide us the capability to network distributed arrays of antennas or sensor satellites which may satisfy a number of mission needs. The communications, surveillance, and targeting capabilities which these advances can facilitate will certainly have great relevance in supporting our warfighting forces.

LightSats could be part of a space-based radar system, perhaps as distributed bi-static elements. Use of synthetic aperture techniques might facilitate resolution at a level of interest to the tactical community. Such an all-weather, day and night system would offer tremendous leverage for battlefield operations.



LightSat might be utilized as distributed bi-static elements of a space based radar system

An autonomous attack, warning, and reaction system could enable a satellite to independently ascertain it is under attack; maneuver out of harm's way; redetermine its position and attitude; and quickly resume preprogrammed operational tasking.



Autonomous operating capabilities may enhance survivability of LightSats

LIGHTSAT PAYOFFS

The DARPA ASTP program is supported by all the Services and by government agencies. Agreements establishing joint programs and cooperation among the Army, Navy, Air Force, and others have either been signed or are in coordination. DARPA is a participant in the United States Space Command Assured Military Space Support Architecture studies and is supporting the Defense Communications Agency's Advanced MILSATCOM Architecture studies. Our intent is not to reinvent the wheel, nor to do an ivory tower analysis which becomes "just another study." We intend to work closely with the Services so that we can all benefit by mutual participation in improving our nation's military space posture.

PAYOFFS

- DEDICATED SPACE SYSTEM SUPPORT TO TACTICAL FORCES

- COMMUNICATIONS
- TACTICAL TARGETING
- WEATHER AND TERRAIN ANALYSIS
- POSITION/NAVIGATION
- ENHANCE UTILITY OF PRECISION MUNITIONS

→

- AUGMENT C3 I CAPABILITIES
- LIGHTEN COMBAT FORCES
- INCREASE "TOOTH-TO-TAIL" RATIO
- ENHANCE MOBILITY AND MANEUVERABILITY
- "SEE DEEP"
- SPAN LARGE DISTANCES
- SUPPORT OPERATIONS IN REMOTE REGIONS
- FACILITATE RAPID FORCE PROJECTION
- EXPLOIT WEATHER AND TERRAIN CONDITIONS TO MAX ADVANTAGE (INSTEAD OF BEING AT NATURES MERCY)

- CAPABILITY TO PROVIDE RAPID & RESPONSIVE SPACE SYSTEMS SUPPORT TO TACTICAL FORCES ANYWHERE ON EARTH

- COUNTER THE SOVIET ABILITY TO LEVERAGE TACTICAL SUPPORT FROM SPACE

Dramatic payoffs could be realized by incorporating small satellites into our overall space architecture

The potential payoffs from LightSats on the battlefields of the future could be enormous. In the coming decades, low and mid-intensity conflicts in remote and isolated places will be the most probable scenarios facing the defense community. It is precisely under such operational scenarios that dedicated space systems, tailored to meet tactical needs, will play a decisive role in determining victory in warfare.

The battlefields of tomorrow will be 4-dimensional worlds, with the high ground of space being a vital component of many military systems. LightSats will also serve as force-multipliers to enhance combat effectiveness in the coming era of budget restrictions and force reductions.

CONCLUSION

To conclude this overview of the Advanced Space Technology Program, we should emphasize that initial efforts will demonstrate available technology for cost-effective and responsive space systems which are dedicated to support tactical forces. These efforts will be followed by the development of more advanced enabling technologies and space system concepts and, with the support of the Services, their eventual demonstration in space.

The fundamental goal of these efforts - to enhance space system capabilities in support of operational commanders - will be achieved by focusing advanced technologies through the lens of military utility.

The DARPA Advanced Space Technology Program is a dynamic and vital component of our nation's military space efforts. In addition, the ASTP contributes to maintaining and invigorating our national technical leadership in space. Indeed, the ramifications of ASTP may be for more diverse and widespread than its directly discernable impact on military space systems.

The ASTP is playing a major role in "priming the pump" of the emerging commercial space industry. Smaller, lighter, more capable space systems will enhance the commercial and scientific space sectors as well as the defense sector.

Cost reduction innovations, such as streamlining manufacturing processes and automating the testing and quality assurance processes, will likewise benefit commercial as well as military space systems. The initiatives being undertaken by the Advanced Space Technology Program will pay dividends well into the twenty first century.

ADDENDUM

Cross-Fertilization and Future Trends

Our paper focussed on concepts and technology initiatives in ASTP which are aimed at enhancing military space systems. Potential areas of synergy with commercial and scientific endeavors in small space systems, and far-term future concepts, will be discussed in this addendum.

Future advanced LightSats, 10 to 20 years from now, will be predicated on significant advances in the areas of power systems, propulsion, and micro-electronics, and will probably also incorporate presently emerging concepts such as tethered constellations, networking and distributed architectures, and new ideas for leveraging off a permanently orbiting space station.

We should emphasize that much of the following discussion is rather speculative and futuristic, and does not necessarily represent present efforts or concepts being pursued by ASTP. Nonetheless, the seeds for far-term future LightSat concepts and capabilities are being sown today by members of the small satellite community in the defense, commercial, and scientific sectors.

Let's first explore some potential near-term commercial and scientific applications of LightSats. Analogous to the point we emphasized above in our discussion of defense applications, we do not foresee LightSats as replacements for large sophisticated commercial satellites. Rather, non-defense LightSats could complement large satellites by expanding coverage in space and time, by facilitating more users, by enabling more direct user tasking ability, and by facilitating more timely dissemination of data.

One potential commercial application for future LightSats may be as observation satellites that could periodically monitor sensitive cargos during transport, provide natural disaster damage assessments and aid coordination and control of relief efforts, aid in search and rescue operations, and provide timely monitoring of environmental events such as the spread of a serious forest fire.

LightSats could complement a major system such as LANDSAT by performing update observations between higher quality LANDSAT images, or by queuing LANDSAT for particular events of interest (volcanic eruption, post-earthquake imaging, etc.).

A lower resolution LightSat image could be parametrically fit to an older higher resolution LANDSAT image, and LANDSAT could be queued to re-observe the dynamic area of interest when the model fitting parameters indicated that a change had occurred. The fair weather requirements for optical systems might be circumvented by use of other wavelength bands (such as IR) or bi-static radar receiver LightSats which performed synthetic aperture synthesis.

Present-day environmental monitoring using multi-spectral imagery (MSI) techniques will undoubtedly evolve towards hyper-spectral capabilities (more observation bands over larger ranges of wavelengths). Packaging these sensors into LightSats, together with capabilities for handling their more demanding ancillary communications and data processing requirements, may be possible in the far-term future. Such satellites would provide data for terrain and ocean analysis to aid military commanders in planning and coordination for tactical operations. Indeed, weather and terrain conditions might someday be a commander's ally instead of plaguing his warfighting effort with uncertainty, as they have throughout history. Similarly, environmental monitoring with future LightSats may facilitate sufficiently fine-grained coverage and timely data dissemination to significantly impact such enterprises as agriculture and commercial fishing.

In addition to observing the earth from space, LightSats can play a role in networking distributed arrays of terrestrially based sensors. Present-day LightSats will have the ability to interrogate unmanned sensors and relay data to ground facilities for processing. Future LightSat may add the ability to perform on-board data processing, multi-user data distribution, and possibly even the ability to task or control sensors based on analysis of the data received from them. Such capabilities could offer tremendous force-multiplying leverage for military operations by integrating large numbers of battlefield and ocean sensors into a commander's tactical information system. A similar leveraging factor could aid efforts in border control and in monitoring sea and air lanes.

Great strides in geophysics, atmospheric and ocean sciences, and other scientific disciplines may result from LightSat-integrated sensor systems deployed in the oceans, in jungles and other isolated areas, and in the polar regions. For example, refined earthquake prediction may result from sufficiently fine-grained sensor networks linked via LightSats.

LightSats may fulfill selected communications needs which are not within the scope of major satellite communications systems. Foremost among these needs will be single voice channel connectivity serving subscribers in remote and isolated regions, and in third world nations. LightSats in low earth orbit might also be employed as relays for disadvantaged users (i.e., those without sufficient power or antenna gain to reach geosynchronous comm-satellites). Organizations that require routine global exchange of large data bases or lengthy messages might employ dedicated E-mail satellites. All of these communications needs are common to both tactical military forces and commercial activities; however, significant cost savings will probably characterize the non-military users who do not require secure, jam-resistant service.

Whether applied to roles in the defense, commercial, or scientific sectors, future LightSats will all require advances in power systems, propulsion, and microelectronics. Present day satellites generate power by solar energy conversion or small nuclear reactors. By far the most common means of generating electrical power on a recurring basis is the use of solar cells. Because they are small, LightSats have been limited in their electric power generating capability, particularly if they employ body-mounted solar arrays. Improvements may be realized by increasing solar cell efficiency and by increasing the available area for mounting cells, perhaps by using deployable or inflatable structures.

In addition to improving the traditional space power systems, new concepts may provide power to LightSats in the future. One such possibility is the use of long conducting tethers to generate power directly from electromagnetic forces in the near-earth space environment. In addition to improved power generation, LightSats could also benefit from improvements in energy storage devices (ie. improved chemical batteries or other new energy storage media).

Propulsion is another area in which great progress may occur in the coming decades. It may prove economically advantageous to boost many LightSats into a low altitude orbit, and subsequently disperse the individual satellites and place them into desired orbits using their own on-board propulsion and maneuvering systems.

Emerging concepts such as electric or plasma propulsion (sometimes called ion propulsion), and laser propulsion schemes using a ground based free electron laser or a space based chemical laser, might be feasible LightSat propulsion systems in the future.

Aero-assisted orbital transfer concepts call for satellites to maneuver using aerodynamic forces in the uppermost atmosphere. Of course, the energy losses due to drag would have to be compensated for by an active propulsion system, but aerodynamic LightSats may some day be a part of our space inventory. Indeed, pushing this idea to one potential limit, the possibility arises that a low earth orbiting LightSat may deploy or inflate a large aerodynamic structure, and use the upper atmosphere to de-orbit in a controlled manner over a desired geographic area. The LightSat turned UAV (unmanned aerial vehicle) could then slowly spiral earthwards over a time scale that may be long enough (days, or possibly even weeks) for it to perform some vital function.

Potential scenarios include de-orbiting a LightSat to provide continuous coverage over an area during a short duration military crisis or conflict, or to provide assistance to a region following a natural disaster.

Demands on communications and computational capabilities will grow commensurately with the proliferation of small satellites. It will probably be necessary to fully utilize space, time, and frequency diversity to accommodate the growing number of system subscribers.

Technological developments in antennas, adaptive beam forming arrays, distributed aperture elements (possibly on separate spacecraft), and demand assigned multiple access systems may aid in meeting this challenge. Sophisticated high density low power micro-electronics will be required to handle the increasing amounts of data being processed by small satellites, as well as the increasing complexities associated with greater satellite autonomy. A potential far-term solution to these needs may result from recent advances in high temperature superconductors.

New materials may superconduct in the cold of space without any supporting cryogenic system at all, provided of course that spacecraft thermal management and solar shielding can be handled. Superconducting microelectronics may facilitate much faster computers (perhaps as much as ten times faster than semiconductor device transition speeds). Additionally, significant reductions in waste heat generation may permit much higher device packing densities compared to semiconductor based integrated circuits

Faster, higher density microelectronics will enable order-of-magnitude improvements in computing power, which could truly revolutionize the capabilities of small satellites.

Significant system capabilities may result by networking a number of LightSats using tether interconnections and radio or laser crosslinks. A degraded or damaged constellation of small satellites may still be able to perform its mission, and the possibility exists that a damaged member of the constellation could be replaced far more easily and at less cost than repairing or replacing a single large satellite. This possibility is appealing for commercial as well as military systems, since a failed member of the constellation may result not only from hostile military action, but also from natural hazards in space or even simply "old age".

The prospect of a manned space station in the coming decades also stimulates some exciting possibilities for small satellites. Commercial and scientific missions might utilize LightSats tethered to the space station. A controllable microgravity environment for space-based chemical manufacturing plants is one possible role for a "smart" LightSat tethered to the space station. It might also prove feasible and cost-effective to perform on-orbit assembly of small satellites from modules. The number of modules and their interconnections might permit such on-orbit assembly of small satellites, even if large complex satellites proved too complicated for final assembly in space.

Several advantages could result from on-orbit satellite assembly at the space station. The satellite would not need the sturdy structural support that a fully integrated satellite requires if it is launched from the ground. The traditional tests (vibration, shock, thermal-vacuum, etc.) would only have to be performed at the box or module level, and functional testing of the fully integrated satellite could be performed on-orbit. Problems during functional testing would be resolved by replacing bad modules, and the defective units could eventually be returned to earth on the Shuttle for repair. This type of modular assembly would also simplify on-orbit repair of deployed satellites that suffered a failure. To be practical, this concept would probably require a reasonable number of identical satellites with a number of modules in common, and this is where LightSat proliferation may tie in. Many modules might be lifted into orbit on a cost-effective heavy booster, which may be more economical than launching LightSats individually or in small groups.

Finally, since defective satellites could be repaired in space, and failed modules returned to earth, the risk of total irreparable satellite failure would be greatly reduced, and the costly procedures presently associated with reliability insurance could be greatly reduced. The need for redundant systems may be eliminated on most satellites. Of course, whether or not the scheme which we have outlined here would prove cost-effective must be determined by rigorous calculations, but future possibilities suggest that cost savings may be realizable.

Robotic LightSats may also find utility, particularly as adjuncts to a manned space station. A defective satellite, or one with depleted expendables, may be recoverable by a robotic LightSat and brought to the space station for repair, refueling, or cannibalization. Small robot satellites with sufficient propulsion might perform services as "space freighters" for modest sized cargo. Fuel pods on large spacecraft might actually be small satellites that autonomously maneuver to a central supply facility for refueling. And a robotic LightSat might find employment as a space "junkman" by helping to collect debris and cleanup low earth orbits.

New concepts for reducing the cost of inherently expensive space systems can utilize small satellites as a test bed. In addition to on-orbit integration of modules, future cost reduction schemes may emphasize standardization of modules, satellite buses, and integration interfaces.

"Health monitoring systems" may be utilized to track all components from the factory to orbit, thereby enhancing final system reliability. Finally, radical new design concepts may lead to dynamically reconfigurable satellite systems which automatically implement graceful degradation strategies as satellites age or become damaged.

The procurement of LightSats for defense missions hinges on a favorable verdict regarding their military utility and cost-effectiveness. Analogously, commercial utility and cost-effectiveness analyses will determine the viable applications for LightSats in non-defense roles.

Both military and commercial advocates of small satellite systems will have to overcome an inevitable degree of inertia and nearsightedness in their prospective user communities. Less than twenty years ago, market indications suggested that personal computers were not needed and would not be well received.

Other examples from history of new technologies that have overcome user inertia and limited initial applications include lasers, the telephone, radio and television, the transistor, and radar. Perhaps LightSats may someday be added to this list. Highly successful, well-received initial demonstrations of small satellite capabilities and utility will be essential to marketing LightSats in defense and commercial roles.

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