Lightsats

Lightsats are satellites that are light enough to be launched by small launch vehicles such as a Scout or Pegasus, or others now in development. Military lightsats could be designed for wartime deployment or replenishment from survivable transportable launchers to support theater commanders. Civil lightsats, and some military ones, would not require transportable launchers; they could be launched by a wider variety of launch vehicles, including larger ones.

The first Soviet and U.S. satellites were lightsats, according to this definition. Explorer I, the first U.S. satellite, weighed only 31 lb but collected data that led to the discovery of the Van Allen radiation belt. But in another sense, the first satellites were fat—as heavy as early launch vehicles could launch. As larger launch vehicles were developed, larger, more capable satellites were developed to ride them. Nevertheless, small satellites continue to be launched for civil and military applications that require only simple functions.

Interest in lightsats has grown recently,[1] partly in anticipation of new rockets designed to launch them at low cost, and, in the case of military lightsats, because of a desire for a survivable means of launching satellites-e.g., transportable launch vehicles too small to launch large satellites.[2]

A few years ago the Defense Advanced Research Projects Agency (DARPA) began to examine lightsats, initially to demonstrate the ability of simple and inexpensive satellites to perform simple but useful tasks, and, more recently, to demonstrate the utility of satellites small enough to be launched from transportable launchers to support theater commanders during a war. DARPA is considering concepts for several types of lightsats--for communica-ions, navigation, radar mapping, and targeting. The Army, Navy, or Air Force may choose to procure similar lightsats for operational use. They would be designed to be affordable as well as small, because many might be needed for replenishment after attrition. “With lightsat, we can undoubtedly put up satellites for less money than it will cost the Soviets to shoot them down,’ said Dr. John Mansfield, while Director of DARPA’s Aerospace and Strategic Technology Office.[3]

SPACECRAFT CONCEPTS

The first lightsat developed by DARPA’s Advanced Satellite Technology Program was a communications satellite, the Global Low-Orbit Message Relay (GLOMR; see figure 4-l). Weighing only 150 lb, GLOMR was launched by the Space Shuttle on October 31, 1985, into a 200-mile-high orbit inclined 57 by degrees.

DARPA has ordered nine more UHF communication satellites from Defense Systems, Inc., the contractor that built the GLOMR. Seven of these, called Microsats, will weigh approximately 50 lb each. These satellites will be launched together into a polar orbit 400 nautical miles high by the Pegasus launch vehicle. Once deployed, they will spread out around the orbit. They will carry ‘‘bent-pipe’ radio repeaters—i.e., the messages they receive will be retransmitted instantaneously to ground stations. The other two satellites will be larger “store/foreward" satellites called MACSATs (forMultiple-Access Communication Satellite). They will weigh about 150 lb each and will be launched together on a Scout launch vehicle. They will store messages received from ground stations and forward (or “dump”) them when within range of the ground stations to which the messages are addressed. The bent-pipe satellites and the first store/foreward satellites will cost DARPA about $8 million excluding launch costs.

Amateur (“ham”) radio operators have built a series of small satellites carrying radio beacons or repeaters, the first of which, OSCAR I, was launched in 1961. Since 1969, the nonprofit Radio Amateur Satellite Corp. (AMSAT) and its sister organizations worldwide[4] have built or designed several of these for scientific, educational, humanitarian, and recreational use by hams. AMSAT, which has only one paid employee, is now building four 22-pound

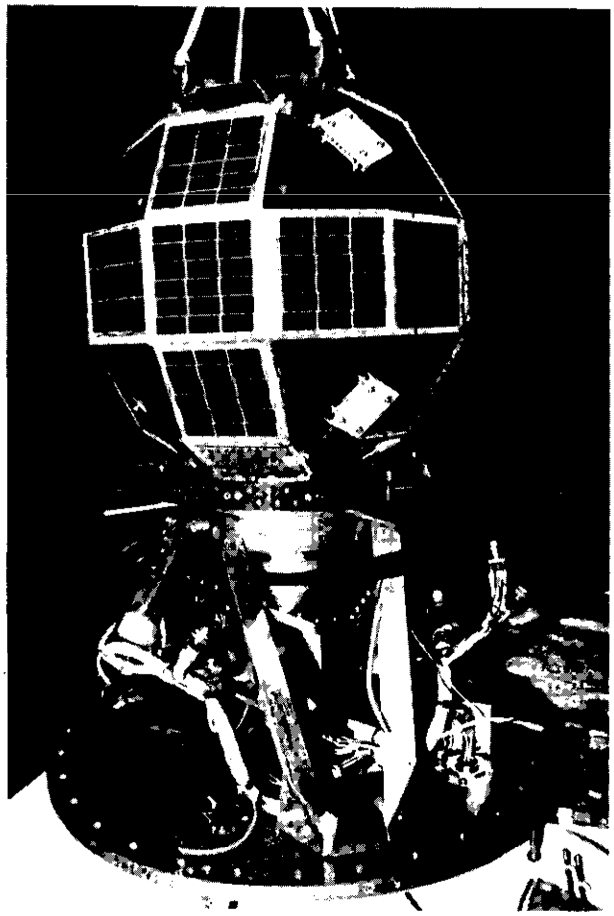
[1] See, e.g., A.E. Fuhs and M.R. Mosier, ‘‘A Niche for Lightweight Satellites,’ *Aerospace America*, April 1988, pp. 14-16., and Theresa M. Foley, “U.S. Will Increase Lightsat Launch Rate to Demonstrate Military, Scientific Uses, ’ *Aviation Week and Space Technology*, Sept. 26, 1988, pp. 19-20.

[2] There is no consensus on whether this is the best approach to assuring continued mission performance in wartime.

[3] Quoted by James W. Rawles, “LIGHTSAT: All Systems Are Go,” *Defense Electronics*, vol. 20, No. 5, May 1988, p. 64 ff.

[4] AMSAT-North America has sister organizations i, Argentina, Australia, Brazil, Britain, @-many, Italy, Japan, Mexico, and the Netherlands. The Soviet Union has also launched satellites for amateur radio operators.

Figure 4-l-The Global Low-Orbit Message Relay (GLOMR) Satellite



SOURCE: Department of Defense.

(l0-kilogram) communications satellites called Microsats[5] (figure 4-2). (These Microsats are unrelated to the above-mentioned Microsats developed for DARPA and to the "microspacecraft" discussed in the next part of this report.) All four satellites are designed to receive, store, and forward digital messages using a technique called packet communications. All four use a standard bus, the Microsat bus. One of the satellites, called PACSAT, is being built for AMSAT. An almost identical satellite called LUSAT is being built for a sister organization, AMSAT-LU, in Argentina. A third satellite, nicknamed Webersat, will carry, in addition to its packet radio repeater, a low-resolution color TV camera designed at the Center for Aerospace Technology at Weber State College in Logan, UT. The fourth satellite, Digital Orbiting Voice Encoder (DOVE), was built for BRAMSAT (AMSAT-Brazil). It will carry a digital voice synthesizer to generate voice messages that can be received by students using inexpensive "scanner' radios.[6]

AMSAT contracted with Arianespace to launch these four satellites together for $100,000. The Ariane 4 launch vehicle will also deploy the UoSAT-D and UoSAT-E amateur-radio satellites built at the University of Surrey in England in addition to the four Microsats and its primary payload, the SPOT 2 photomapping satellite.[7] The launch, originally scheduled for June 1989, has been postponed until January 1990, at the earliest.

Microsats are among the smallest communications satellites ever built. They are lightsats, because they are designed to perform relatively simple functions. But they are also fatsats, because they are heavier and larger than they would be if built by methods usually used for more conventional (and more expensive) satellites. Assembly of some Microsat subsystems is literally a cottage industry. Although some printed circuits are being built for Microsats by a contractor using high-tech methods, others are being built in the homes of Amateur radio operators all over the country. When they volunteer to assemble printed circuits, AMSAT sends them the instructions.

CONCEPTS FOR PHASED ARRAYS OF SPACECRAFT

Groups of small satellites could collectively provide communications or radar capabilities that could otherwise be provided only by a large satellite. To do so they would have to operate coherently as elements of a phased array: all satellites must relay the signals they receive to a satellite or ground station that can combine them in a way that depends on the relative positions of the satellites, which must be measured extremely accurately. When transmitting, the satellites must all transmit the same signal,

[5] See Courtney Duncan, "The AMSAT-NA Microsats," 73 *Amateur Radio,* May *1989,* pp. 83-84, and Doug Loughmiller and Bob McGwier, "Microsat: The Next Generation of OSCAR Satellites—Part l," *QST*, May 1989, pp. 37-40.

[6] The digital voice synthesizer is similar to the DIGITALKER developed at the University of Surrey in England for use on the UoSAT-OSCAR-9 and UoSAT- OSCAR-11 amateur-radio satellites built there.

[7] Jeff W. Ward, "Experimental OSCARS," *QST, May* 1989, p. 62 ff.

Figure 4-2--Microsat: A 22-lb Communications Sa e e o Amateu Ham Rad o Ope ato s

(1) Flight model beside Leonid Labutin, UA3CR.
(r) Close-up view. (Copyright Radio Amateur Satellite Corp.)
Photos: Andrew C. MacAllister, WA5ZIB.

but each satellite must delay its transmission by a period that depends on its relative position.

The Air Force has considered “placing large phased arrays in space with major components of the arrays not rigidly connected to each other” (see figure 4-3), because “If we can achieve coherence among these components, phased arrays can be spread out over very large volumes in space, giving them an unprecedented degree of survivability. It therefore may be possible to create a phased-array device (e.g., a space-based radar) that we can place into space and enhance simply by adding more relatively inexpensive elements whenever the threat increases and budget pressures permit.”[8] If small enough, each element could be launched by a small launch vehicle.

If a large radar or communications satellite were divided into several modules, “crosslink” equipment for communications among the modules would have to be provided, which would add some weight and cost. Aside from this, historical cost data indicate that a communications mission payload might cost less if divided into several smaller payloads of equal aggregate weight and power.[9] The same might be true of radar equipment. Each module would need its own bus, but the cost data also indicate that several small busses would probably cost less, or no more, than a single bus of equal aggregate weight.[10] Learning and production-rate effects could make the small modules and busses even less expensive. Economies of scale in launching might make it economical to launch as many as possible on a large launch vehicle, but they could be launched individually on small launch vehicles if desired-e. g., in wartime, if peacetime launch facilities have been damaged.

Coherent operation of several satellites requires relative positions to be measured with errors no greater than a fraction of a wavelength of the radiation to be sensed or transmitted. The accuracy required for coherent operation of several satellites as a microwave radar or radiotelescope has already been demonstrated.[11] Coherent operation of several

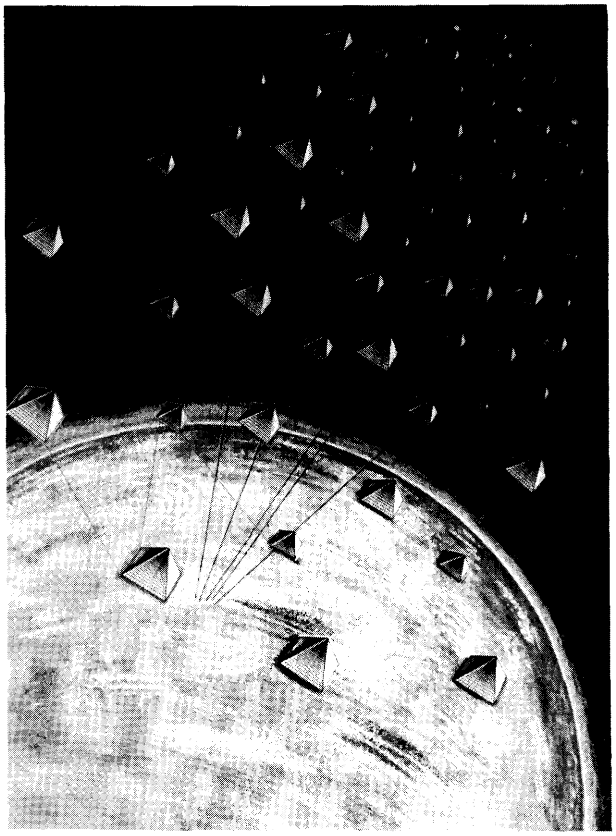
[8] Headquarters, Air Force Systems Command, *Project Forecast II Executive Summary* (Andrews Air Force Base, MD: Headquarters, Air Force Systems Command, undated). This concept is described in greater detail in the classified final report. AFSC-TR-86-008; see pp. PS-30.01 to PS-30.19 of Annex D of vol. IV, which authorized readers may request from the Defense Technical Information Center (accession number AD-C039 642).

[9] P. Hillebrandt et al., *Space Division Unmanned Space Vehicle Cost Model Sixth Edition*, SD TR-88-97 (Los Angeles AFB, CA: Headquarters, Space Systems Division, U.S. Air Force Systems Command, November 1988); distribution limited to U.S. Government agencies only.

[10] Ibid.

[11] M.A. Dornhein, "TDRS, Ground Antennas Link for Radio Astronomy Observations," *Aviation Week and Space Technology, Dec.* 1, *1986*, pp. 32-33.

Figure 4-3—Sparse Array of Satellites Could Provide Detailed Radar Maps (Artist's Concept)



SOURCE: U.S. Air Force.

satellites as a ladar or optical telescope is beyond the state of the art. However, someday it may be feasible to launch several telescope modules, each smaller than the Hubble Space Telescope, and assemble them in space (or allow them to assemble themselves) into a rigidly connected phased array[12] that would operate as an optical telescope with better light-collecting capability and resolution than the Hubble Space Telescope. If technology advances further, two or more such arrays, not rigidly connected to one another, could operate coherently to further increase light-collecting capability and, especially, resolution.[13]

A scientist at the Jet Propulsion Laboratory (JPL) of the California Institute of Technology (CalTech) has proposed a less ambitious phased-may radiotelescope that could be begun today: an Orbiting Low-Frequency Array of 6 or 7 satellites in a formation 200 km across (see figure 4-4). It could map astronomical sources of radio signals with wavelengths longer than 15 meters; such signals cannot penetrate the Earth's ionosphere to reach ground-based radiotelescopes. The angular resolution of the proposed array could be comparable to that of a dish antenna 200 km across. JPL estimates that each satellite would cost about $1.5 million and weigh less than 90 kg (200 lb) if cylindrical, or 45 kg (100 lb) if spherical[14] They must be launched to a circular orbit at least 10,000 km high, so the equivalent weight to low orbit would be about 170 lb for the spherical satellite.

LAUNCH REQUIREMENTS

Operational launchers for military lightsats must meet several requirements, the most distinctive being survivability in high-intensity (if not nuclear) conflict. Such survivability is required of U.S. strategic and theater missile launchers, and operational lightsat launchers might adopt some of their features. Like the rail-mobile launcher for the Soviet SS-24 intercontinental ballistic missile (ICBM), the similar launcher being developed for U.S. Peacekeeper (M-X) ICBMs, and the Hard Mobile Launcher being developed for the Small ICBM ("Midgetman"), lightsat launchers could pursue survivability through mobility. They could also employ concealment, as do the Pershing 2 launcher and submarines (e.g. Trident) that launch ballistic missiles.

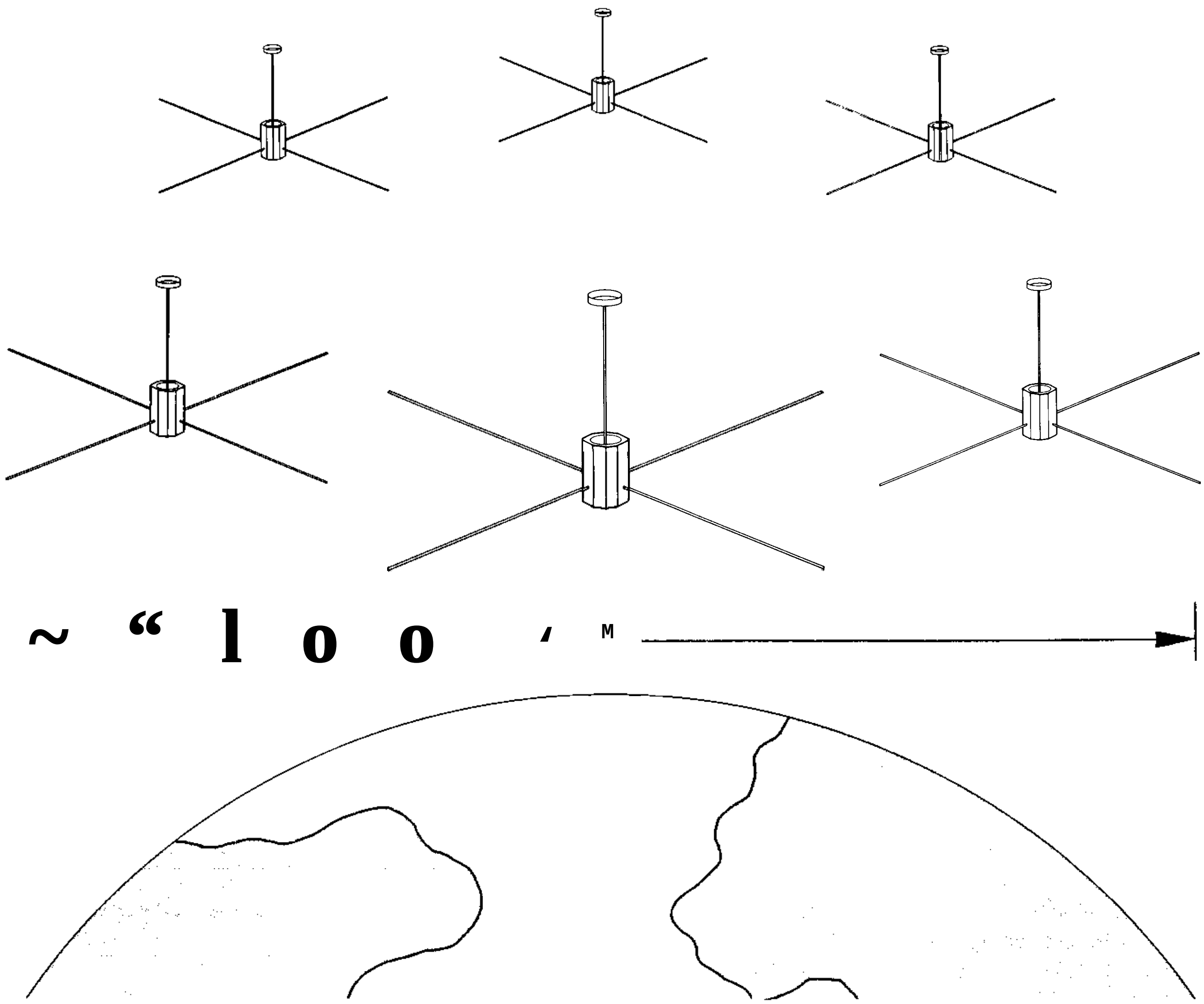
Operational military lightsat launchers would probably be required to launch on short notice and to sustain higher launch rates than typical space launch facilities do. On the other hand, lightsat launch vehicles would be useful with less lift capability than most launch vehicles have, although DARPA has said the Scout launch vehicle lifts too little to be useful as an interim launch vehicle for launching developmental lightsats, and the Scout does not have the survivability and launch rate desired for wartime use. The Pegasus launch vehicle may provide an innovative means of improving launch flexibility and survivability.

12 Such as the proposed Coherent System of Modular Imaging Collectors (COSMIC) described by the National Research Council in Space *Technology to Meet Future Needs* (Washington, DC: National Academy Press, 1987), p. 39.

13 Ibid.

14 Tom Kuiper. "Sub-millimeter Waves, " in NASA/OAST & SDIO/IST, *Micro Spacecraft for Space Science Workshop-Presentations*, California Institute of Technology Jet Propulsion Laboratory, July 6-7, 1988; pp. 136-142.

Figure 4-4-Orbiting Low-Frequency Array of Radioastronomy Satellites (Artist's Concept)



SOURCE: California Institute of Technology, Jet Propulsion Laboratory.

Civil lightsats and developmental military lightsats would not require transportable launchers.

LAUNCH SYSTEM OPTIONS

Existing Launch Vehicles

Civil lightsats, or developmental military lightsats, could be launched-alone or co-manifested with other payloads-on currently operational launch vehicles larger than the Scout. If they are small enough, they could be launched by the Scout.

Air-Launched Vehicles

The communications satellites now being developed by DARPA are very light; several can be launched on the Pegasus air-launched vehicle (ALV). The Pegasus ALV is being developed by Orbital Sciences Corp. (OSC) and Hercules Aerospace Corp. as a $50 million privately funded joint

Figure 4-5-Pegasus Launch

The Pegasus air-launched vehicle is released from a modified B-52 aircraft operated by NASA's Dryden Flight Research Facility (artist's concept).
SOURCE: Orbital Sciences Corp.

venture. DARPA will pay OSC $6.3 million to provide the launch vehicle for a government demonstration launch. This price includes neither the cost of using NASA's B-52 as an ALV carrier (see figure 4-5) nor the cost of safety support from the Air Force's Western Test Range. Pegasus is expected to be able to launch a 335-kg (738-lb) payload into an orbit 500 km (270 nmi) high and inclined 25 degrees, or a 244-kg (537-lb) payload into a polar orbit 500 km high (see figure 4-6).

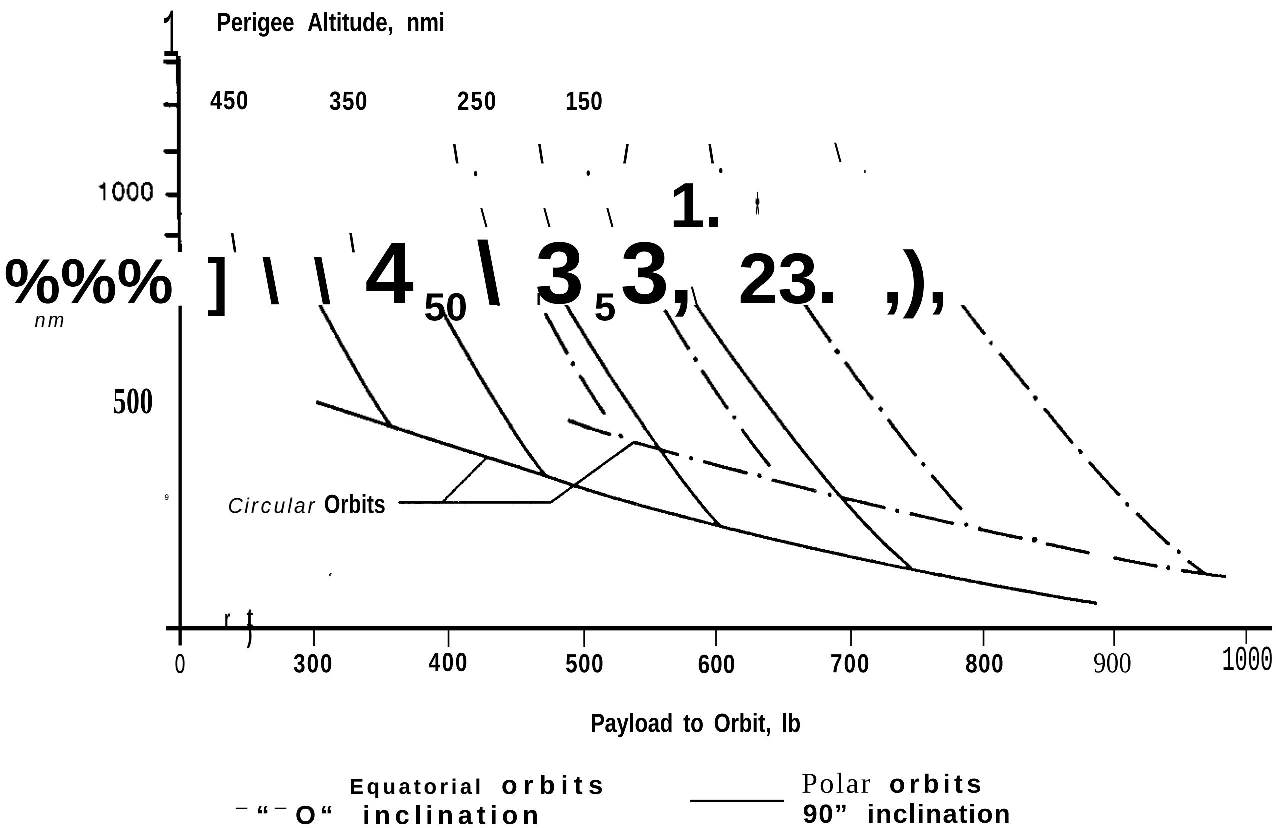
DARPA originally intended to launch the Microsats on the first Pegasus launch, but has decided to launch them on the second launch, perhaps late in 1989. On its first flight, now scheduled for January 1990, Pegasus will carry:

1. a 150-lb Navy communication satellite,
2. a NASA scientific experiment payload, and
3. instrumentation to evaluate the performance of the ALV.

DARPA's contract has four launch options remaining, and OSC has offered to add six additional launch options to the contract.

OSC and Hercules also expect Pegasus can launch lightsats into geostationary orbit; they recently signed an agreement with Ball Aerospace to launch two BGS-1OO Ball geostationary satellites in late 1990 or early 1991. OSC estimates each launch will cost between $6 million and $8 million, and that each of the satellites, which will weigh about 400 lb and carry a 400-watt single-channel transponder, will cost between $5 million and $8 million. OSC estimates each mission (satellite, launch, and support) will cost about $20 million. The satellite design

Figure 4-6-Projected Performance of Pegasus: Payload v. Orbital Altitude and Inclination



SOURCE: Orbital Sciences Corp.

is modular; Ball is developing larger versions with more transponders or more power per transponder.[15]

Standard Small Launch Vehicle

Last year, DARPA issued a Request for Proposals to develop a transportable ground-launched Standard Small Launch Vehicle (SSLV) capable of launching 1,000 lb of payload to a polar orbit 400 nmi high. DARPA recently awarded a contract to Space Data Corp. (a subsidiary of OSC) for development, one launch (from Vandenberg Air Force Base in the fall of 1991), and options for four more. The first stage of the vehicle proposed by Space Data Corp. will use a solid rocket motor developed for the Peacekeeper ICBM by Morton Thiokol. The second, third, and fourth stages will be the first, second, and third stages of Pegasus, without the wings. OSC is also developing a commercial version of the SSLV, called Taurus.

Other small launch vehicles have been developed or proposed by companies that performed Phase 1 SSLV studies for DARPA. Space Services, Inc. (SSI) developed a launch vehicle called Conestoga, which uses clustered Castor solid rocket motors. The first Conestoga was successful on a sub-orbital flight, but the second failed shortly after launch on November 15, 1989. LTV Aerospace, which produces the Scout, could produce an upgraded version. Lockheed Missiles and Space Co. proposed a launch vehicle that would use the first- and second-stage motors from Poseidon C3 fleet ballistic missiles and Morton Thiokol Star 48 motors for the third stage. Lockheed estimated that the vehicle could be available in two years and could launch a 770-lb

[15] "Pegasus, Ball to Launch Communication Satellites Into Geosynchronous Orbit," *Aviation Week and Space Technology*, June 12, 1989, p. 64, and *Military Space*, June 19, 1989, p. 8.

payload from a land-based launcher to a 250-mile high orbit inclined 28 degrees.[16]

Other Options

The U.S. Naval Research Laboratory (NRL) is developing a concept for a sea-launch system to launch a partially submerged launch vehicle from a platform towed out to sea.[17] This system, called SEALAR (SEA Launch And Recovery) might provide the survivability required by lightsats. Sea-launch systems have been tested, to different degrees, by the U.S. Navy (Project Hydra), Truax Engineering[18] (SEA DRAGON, SUBCALIBER), and StarStruck (now American Rocket Co.). DARPA is not known to be considering a sea-launch system for its Advanced Satellite Technology Program, but such a system might prove attractive to the Navy in the future.

Storage, shipment, and mobile basing of small launch vehicles could be made safer by using hybrid rocket motors—rocket motors that use liquid oxygen to burn solid fuel, which can be inert (nonexplosive). American Rocket Co. (AMROC) of Camarillo, CA, has developed a throttleable, restartable, 70,000-lb thrust hybrid rocket motor, the H-500. On its first launch attempt (October 5, 1989), the motor failed and the prototype sounding rocket it was to power collapsed and burned at Vandenberg Air Force Base, CA. It is noteworthy that it did not explode, and did very little damage to the pad.

The sounding rocket, a prototype of AMROC'S planned Industrial Research Rocket, carried a payload designed by AMROC for a Strategic Defense Initiative experiment and a prototype reentry vehicle developed by the Massachusetts Institute of Technology (MIT) Space Systems Laboratory. The reentry vehicle was to deploy an umbrella-like structure made of space-suit material and decelerate to a soft landing in the Pacific Ocean, where it was to be recovered.

AMROC is developing a larger sounding rocket and an even larger Industrial Launch Vehicle, the largest version of which is being designed to launch a 4,000-lb payload into low Earth orbit. AMROC is not specifically designing the launch vehicle for survivable basing (although this is not precluded) and has not entered DARPA's SSLV competition. Before the sounding rocket failure, AMROC expected a frost launch late in 1990.

AMROC is also developing a larger hybrid motor for a larger launch vehicle, as well as a smaller hybrid motor for various applications, possibly including use on projectiles launched from electromagnetic launchers (discussed below).

General Technology Systems (GTS) is developing a small launch vehicle called LittLEO to launch lightsats. It is expected to be able to launch almost a tonne (2,200 lb) of payload into a polar orbit 300 kilometers (162 nautical miles) high. First launch is planned for 1992, probably from Andoya, Norway. GTS quotes a price of nine million pounds sterling per launch, which is equivalent to roughly $6,400 per pound to LE0.[19]

E'Prime Aerospace Corp. (EPAC) is developing a series of launch vehicles for launching payloads weighing from 1,000 to 20,000 lb into LEO and up to 8,000 lb into geostationary Earth orbit (GEO). EPAC quotes a prices of $12 million per launch for the smallest launch vehicle and $80 million for the largest.[20] EPAC plans to launch from Cape Canaveral Air Force Station, FL, and from Vandenberg Air Force Base, CA. A first launch is planned for 1992.

The Soviet Union is developing a launch vehicle called "Start" for launching lightsats. Start would use guidance and propulsion systems developed for the SS-20 ballistic missile and could be launched from a mobile launcher, carrying 300-lb payloads to orbits 500 km high. Space Commerce Corp., in Houston, is seeking customers for Technopribor, which is developing Start, and quoting a price of about $5 million to $6 million per launch. Technopribor estimates a test launch could be conducted in 1991.

Lightsats can also be launched as "piggyback" payloads on launch vehicles carrying larger primary payloads. Many U.S. and foreign launch vehicles have done this for years. Arianespace has developed

16"Lockheed Will Develop Small Military Booster Using Poseidon C3 Hardware," *Aviation Week and Space Technology,* Sept. 26, 1988, p. 18.

17NRL, Naval Center for Space Technology, briefing for OTA staff, Feb. 17, 1989.

18Capt. Robert C. Truax, USN (ret.), "Commercial View on Launch Vehicles," *Space Systems Productivity and Manufacturing Conference [V* (El Segundo, CA: Aerospace Corp., Aug. 11-12, 1987); pp. 55-69.

19Ian Parker, "Getting There Cheaply," *Space,* vol. *5, No. 4,* July-August 1989, pp. 45-48.

20Ibid.

procedures to do so routinely with the Ariane 4 launch vehicle, which, as noted above, is scheduled to launch six amateur-radio satellites in addition to the SPOT 2 photomapping satellite on January 19, 1990. General Dynamics is planning to offer a similar service using its commercial Atlas launch vehicle, which could launch, in addition to a primary payload, one 3,000-lb satellite or several smaller lightsats to LEO, or a 2,000-lb payload to geostationary transfer orbit.[21] This service could be offered in late 1991 for about $6,000 per pound to LEO; the primary payload owner may reserve the right to approve the price offered.[22]

Someday, small lightsats might be launched on laser-powered rockets (discussed below). Lightsats could also be launched on vehicles proposed for launching larger payloads or crews--e.g., the Advanced Launch System, the Advanced Manned Launch System, and NASP-derived vehicles.[23] Of these, only National Aero-Space Plane (NASP)-derived vehicles (NDVs) are intended to provide a survivable capability for wartime launch.

ISSUES

Are lightsats the most economical answer to the problem of satellite vulnerability? Replenishing satellites in wartime is only one of several partial solutions; others include hardening satellites and stockpiling spare satellites in orbit during peacetime,[24] as well as arms control, actively defending satellites, and reducing reliance on satellites for support of military operations.[25]

What military requirements could lightsats satisfy? An Air Force officer responsible for space system planning said, "The challenge to the small satellite community has been to get out of the mold of a solution looking for a problem; that is, what missions will a small satellite support."[26] According to the previous Secretary of the Air Force, "The decision on whether a system is 'small' depends on such things as orbit, mission, requirements, and technology capabilities. When these factors properly converge, we have built Smallsats . . . . What we want are a realistic set of requirements and concepts for smaller systems."[27] Several concepts have already been proposed, the most grandiose of which are being considered by the Strategic Defense Initiative Organization: ''BrilliantPebbles" or larger space-based missile interceptors, "Brilliant Eyes" (space-based space-surveillance satellites that would demonstrate Brilliant Pebbles technology—see box 4-A), decoys for Brilliant Pebbles, and "Small Dumb Boosters" (orbital transfer stages with which Brilliant Pebbles could rendezvous and mate).

Could lightsat technology and launch vehicles benefit civil applications? They already have. For example, for two decades amateur radio operators have built and used lightsats for recreational, educational, and public-service communications. Conceivably, networks of tens or hundreds of lightsats could provide continuous global communications or navigation services commercially. There is some commercial interest in concepts that would require only a few lightsats.[28][29]

Since Sputnik I and Explorer I, science has benefitted from lightsats and will continue to benefit-more so if launch costs are reduced. Medium-sized multi-mission remote-sensing satellites have used some instruments, such as the Scanning Multichannel Microwave Radiometer on Seasat-1,[30] that are light enough to be mated to a

[21] To reach geostationary orbit (GEO) from geostationary transfer orbit (GTO), the payload must have an orbital transfer stage.

[22] Ian pinker, op. cit., footnote 19.

[23] See U.S. Congress, Office of Technology Assessment, *Round Trip to Orbit: Human Spaceflight Alternatives*, OTA-ISC-419 (Washington, DC: U.S. Government Printing Office, August 1989).

[24] See, for example, the speech that the Honorable Edward C. AMridge, Jr., Secretary of the Air Force, prepared for a luncheon at the Aviation Club, Crystal City, VA, Sept. 15,1988, and Col. Charles Heimach, USAF, Speech to Second Annual AIAA/USU Conference on Small Satellites, Utah State University, Logan, UT, September 1988.

[25] See U.S. Congress, Office of Technology Assessment, *Antisatellite Weapons, Countermeasures, and Arms Control*, OTA-ISC-281 (Washington, DC: U.S. Government Printing Office, September 1985); reprinted in Office of Technology Assessment, *Strategic Defenses* (Princeton, NJ: Princeton University Press, 1986).

[26] Col. Charles Heimach, USAF, op. cit., footnote 24.

[27] Hon. Edward C. Aldridge, Jr., op. cit., footnote 24.

[28] Fuhs and Mosier, op. cit., footnote 1.

[29] The Center for Innovative Technology of the Commonwealth of Virginia has commissioned economists at George Mason University to assess potential markets for small satellites. This study is nearing completion.

[30] A.R. Hibbs and W.S. Wilson, "Satellites Map the Oceans, " *IEEE Spectrum,* October 1983, pp. 46-53.

Box 4-A—Brilliant Eyes?

Lawrence Livermore National Laboratory (LLNL) is developing a new class of electronic high-resolution wide-angle TV cameras that, from an altitude of 1,000 km (610 mi), could image a land area the size of the state of Virginia and show individual buildings. The first prototype camera, completed in 1987, has optics that are about 1 ft in diameter and 16 in long, excluding electronics. With improved electro-optical components, its resolution would be comparable to or slightly better than that of the French SPOT satellite (about 10 m) from a comparable altitude (832 km). At a lower altitude it could show greater detail but would have a smaller field of view. On Earth, it could be used as a telescopic TV camera to record the tracks of meteors and low-altitude satellites against the night-time sky.

LLNL has also developed a preliminary design for a miniature version of this camera compact enough for use as a satellite navigation system. The system is designed to get periodic position updates by viewing many stars at the same time. The total mass of the system is expected to be less than 250 grams (about half a pound). LLNL expects that "this [wide-field-of-view] system, with its combination of high resolution and high light collection capability, will also find applications in robot vision and smart munitions.

SPOT Imagery of the Pentagon and the White House
Lightsats Could Produce Comparable Imagery

SOURCE: U.S. Geodetic Survey.

[1] LLNL, *Energy and Technology Review*, July-August 1988, pp. 88-89.

lightsat bus to become a lightsat for meteorology and oceanography. Arrays of lightsats could someday use interferometric (phased-array) and aperture-synthesis techniques to provide high-resolution radar or microwave imagery for Earth-resources mapping or "mediasat" applications.[31] This might be more economical than using a large, monolithic satellite; predicting an arrays' relative economy would require comparing cost estimates based on detailed designs.

[31] See U.S. Congress, Office of Technology Assessment, *Commercial Newsgathering From Space*, OTA-TM-ISC-40 (Springfield, VA: National Technical Information Service, May 1987).