COMPENDIUM OF SMALL CLASS ELV CAPABILITIES, COSTS, AND CONSTRAINTS

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The small class of expendable launch vehicles (ELV's) is the most dynamic and has experienced the largest entry of commercial entrepreneurial activity both in the United States and abroad over the past few years. Small class ELV's can deliver payloads weighing up to approximately 1,000 lbs. to low earth orbit. Until 1989, the only flight demonstrated vehicles in this class were the U.S. Scout, the Japanese MU IIS, and the Chinese Long March I. All of these vehicles were developed under government contracts to meet specific government requirements. The Scout vehicle leads the pack with an impressive history of 112 flights, with 98% reliability over the last 20 years.

With the emergence of a viable commercial small class market in the mid-1980's, industry has responded by offering a range of new services which can be divided into two categories: commercially designed vehicles based on existing rocket motors and components; and vehicles designed and developed primarily by commercial entities. E'Prime's EPAC family and Space Service, Inc.'s Conestoga family, both manufactured in the U.S., are examples of vehicle configurations utilizing existing solid rocket motors. Sweden/Arianespace are considering development of a launch vehicle, the Mariane, which would utilize Ariane components. The American Rocket Corporation's (AMROC) Industrial Launch Vehicle and the Orbital Science Corporation's Pegasus are examples of commercially developed vehicles; each targets 1989 as the year for their vehicle's maiden flight. The AMROC vehicle employs hybrid propulsion technology that draws on fundamental technological research generated by the U.S. Government, but specifically developed by AMROC through applied research and development. The Pegasus, a winged booster that will be launched from a NASA/Boeing B-52 bomber, is under contract with the U.S. Defense Advanced Research Project Agency (DARPA).

U.S. Government demand for small class launch services is estimated at 10 flights/year for national security missions, and 2-5 flights/year through 2000 for NASA civilian scientific payloads. The commercial and foreign demand for this class of services is scoped at 10 flights/year through 2000. Both NASA and DARPA are investigating programs to provide flight demonstration opportunities for the new commercially developed rockets. NASA has been evaluating the feasibility of developing a program that would provide a series of low cost, relatively high risk payloads. If this program materializes, NASA would seek to competitively procure commercial launch services for these payloads using selection criteria which emphasizes cost and innovativeness and assigns a lower priority to experience. Status on NASA's efforts on this program will be discussed. Success of the various launch service providers in this class will prove to be a litmus test for the costs and capabilities associated with the various vehicles, with strong emphasis on the constraints impacting their development and widespread utilization.

Compendium of Small Class ELV
Capabilities, Costs and Constraints

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The small class of expendable launch vehicles (ELV's) is the most dynamic and has experienced the largest entry of commercial entrepreneurial activity both in the United States and abroad over the past few years. Small class ELV's can deliver payloads weighing up to 3,000 pounds to low earth orbit. Until 1989, the only flight demonstrated vehicles in this class were the United States Scout, Atlas E/F, and Titan II; the Japanese MU IIS; and the Chinese Long March I. All of these vehicles were developed under government contracts to meet specific government requirements. The Scout vehicle leads the pack with an impressive history of 112 flights, with 98% reliability over the last 20 years. With the emergence of a potential commercial small class market in the late 1980's, industry has responded by offering a range of new services which can be divided into two categories: vehicles that are actually in development and under contract for launch and vehicles that are in various stages of conceptual design with no firm launch commitments. U.S. Government demand for small class launch services has been estimated at 10 flights/year for national security missions, and 2-5 flights/year through 2000 for NASA civilian scientific payloads. The commercial and foreign demand for this class of services has been scoped at 10 flights/year through 2000. Both NASA and DARPA are investigating programs to provide flight demonstration opportunities for the new commercially developed rockets. Success of the various launch service providers in this class will prove to be a litmus test for the success of ELV commercialization. Included in the discussion are the costs and capabilities associated with the various vehicles, with strong emphasis on the constraints impacting their development and widespread utilization. Also included in the paper is an overview of international launch vehicle development plans in the small class and a discussion of the market for small ELV's in the 1990's.

Introduction

Since the 1960's expendable launch vehicles (ELV's) have been manufactured in the United States under contracts with either the National Aeronautics and Space Administration (NASA) or the Department of Defense (DOD) to support government mission requirements. Commercial satellite operators contracted with NASA to launch their payloads, first on NASA ELV's and later in the 1980's on the Space Shuttle. The U.S. Government held title to all ELV production tooling and special test equipment and allowed ELV manufacturers use of the equipment solely to produce vehicles for the government. In the late 1970's a decision was made to phase out of ELV's and rely solely on the Space Shuttle for government launch needs. By 1983 the transition was nearly complete. The government ceased procurement and research, development and production of ELV's. With the passage of the Commercial Space Launch Act in 1984 (P.L. 98-575) Congress authorized federal agencies to make national ELV technology and infrastructure capability available to the private sector for commercial application. The domestic commercial ELV industry's initial response was lukewarm, since the Shuttle was providing commercial launch services at a very attractive price, and the French Ariane ELV was entering the commercial market at the same time.

The fate of U.S. ELV's was altered in 1986 by the Challenger, Titan 34D and Ariane accidents and the decision to preclude launch of commercial satellites on the Space Shuttle once the vehicle returned to flight. A critical lesson learned from the Challenger and Titan accidents was that the United States cannot place total reliance for access to space on any one type of launch vehicle. Accordingly, the Mixed Fleet Strategy, which utilizes the unique capabilities of the Space Shuttle and a range of unmanned launch vehicles, is being employed to support the mission requirements of the U.S. civil government and national security sectors. In accordance with national policy directives NASA is implementing its ELV Mixed Fleet Program, initiated in 1987, by procuring launch services competitively from the domestic commercial sector in three vehicle performance classes: Small ELV (SELV) class (e.g., Scout), Medium ELV (MELV) class (e.g., Delta), and Intermediate ELV class (e.g., Atlas/Centaur). Under current planning, large class vehicles (e.g., payload capability of 40,000 pounds or greater to low earth orbit) will be acquired through the DOD, since launch vehicle services in this class are not commercially available at present. The commercial market has shifted to a point where domestic launch service providers are willing to invest capital necessary to compete in the international marketplace. Based upon the costs associated with ELV development, manufacture, and launch operations the greatest number of entrepreneurial activity to date appears to be in the small ELV performance class where capital development costs are lowest.

Existing Domestic Small ELV's

NASA and the Department of Defense (DOD) have been the developers and primary users of three small ELV's, specifically, the Scout, Atlas-E and Titan II. A brief description of each vehicle and its flight history is summarized below.

SCOUT

NASA's Langley Research Center initiated development of the Scout in 1958. The first Scout test flight was held on July 1, 1960, and in 1961 Scout became the first solid-fueled rocket to carry a payload to orbit. Improvements have increased Scout payload capacity from 130 pounds to 475 pounds in a nominal 300 mile orbit. There have been 112 Scout flights over some 29 years, with 19 consecutive successes since May 1976, and 56 out of 57 mission successes since September 1967. LTV Missiles and Electronics Group (LTV) produces and launches the Scout for the U.S. Government. The current Scout is a four-stage solid propellant vehicle with a capability to lift up to 600 pound payloads depending on launch site and mission. Scout incorporates an Algol IIIA first stage; a Castor IIA second stage; an Antares IIIA third stage, and an Altair IIIA fourth stage. United Technologies Chemical Systems Division produces the first stage and all other upper stages are purchased from Morton Thiokol. Three launch sites have been used to support Scout launches: Wallops Island in Virginia, Vandenberg Air Force Base (VAFB) in California and the Italian San Marco Range (SMR) off the coast of Africa in Kenya. The Scout has been used primarily to launch NASA scientific missions, Navy and USAF satellites. The U.S. Government will launch its remaining six vehicles, after which the Scout vehicle will be manufactured and commercially marketed by LTV Missiles, Inc. Scout II is an LTV/Italian venture independent of NASA's Scout Program. LTV's memorandum of understanding with the Italian SNIA BPD calls for the Scout core to be built in the United States and be combined with new strap-on boosters, improved upper stage motor, and a larger payload fairing from Italy. The Scout II strap-on solid boosters are derivatives of those used on the French Ariane. The more powerful Scout II is expected to double the payload capability of today's Scout and yet require only minimal modifications to existing launch facilities. LTV and SNIA BPD intend to continue to focus on government payloads (U.S./Italian/European); however, the Scout II will be offered commercially at a cost of approximately $15M per dedicated mission.

ATLAS-E

Atlas-E and -F vehicles were being developed along with Atlas-D's in the late 1950's as U.S. intercontinental ballistic missiles (ICBM). The Atlas-E and -F were deployed in U.S. missile silos through the mid-1960's when they were replaced by the Minuteman. The Atlas-F was primarily used to support the Advanced Ballistic Re-Entry Systems (ABRES) program for some 51 launches between 1965 to 1974. The Atlas-E, however, was rarely used until the late 1970's when the remaining vehicles were refurbished for use as space launch vehicles. Atlas-E is a one and one-half stage liquid oxygen/liquid hydrocarbon fueled launch vehicle; does not have a restart capability; and can only deliver payloads to low altitude orbital injection points. Spacecraft kick motors are then used to achieve final injection into the desired orbit. The Atlas-E is radio guided. The Atlas-E has a 92% overall reliability record (87 launches, 80 successful). After a series of Atlas-E propulsion system failures, the Canoga Overhaul Program (COP) was started in 1981 to completely overhaul and re-hot-fire all Atlas MA-3 engines. All COP engines have either performed satisfactorily or been installed on remaining Atlas-E's. Since the COP was initiated, the vehicle has had 12 successful launches. The Atlas-E has been used primarily to launch USAF and NOAA weather spacecraft and is capable of placing 1,750 pounds into polar low earth orbit when assisted by an apogee kick motor. Most of the nine remaining USAF vehicles will be used to launch NOAA TIROS satellites and USAF Defense Meteorological Satellite Program (DMSP) satellites by 1992. USAF funding to support the VAFB launch facility will end subsequent to FY 1989, after which the cost of facility support will be borne by the users. NOAA, DMSP and other payloads will be transitioned to the Titan II to satisfy future mission requirements.

TITAN II

The Titan, designed originally by the USAF for its missions in 1955, has since been upgraded and configured in several different ways. The Titan I was a two-stage intercontinental ballistic missile (ICBM) using liquid oxygen and RP-1. The Titan II (larger than a Titan I, but also an ICBM) was first deployed in 1962 and utilized a storable liquid propellant, hydrogen and nitrogen tetroxide. The Titan II was later converted and used to launch the Gemini missions from 1964-1966, demonstrating a 100% reliability with 12 successful flights. The Titan II ICBM's were deactivated from 1982 through 1987 and placed in storage at Norton Air Force Base until they are needed for flight. The modifications of the Titan II vehicle retain the airframe, engines, and guidance from the ICBM and inherit the payload fairing, forward skirt structure, attitude control, electrical and ordnance subsystems from the Titan III space launch vehicle. The Titan II will be launched from the Western Test Range and place approximately 4,200 pounds into a polar low earth orbit. A total of 55 vehicles are available for refurbishment, although the current USAF/Martin Marietta contract is only for refurbishment of 14 vehicles through 1995. The goal of this refurbishment program is to maximize the use of existing government hardware while minimizing launch complex modifications and total launch costs. The Titan II will be used to launch the DMSP missions, other military payloads and beginning in 1993 the NOAA-L, M, and N TIROS polar meteorological satellites. The first successful launch of a refurbished Titan II occurred in September 1988. The program has the capability of launching three missions per year.

It is evident that the current U.S. ELV's, developed under government contracts, are based on the technology first developed in the 1960's. Individual vehicles have been stretched; additional strap-on motors provide extra lift capability; rocket engines have been uprated; but no new technology is being utilized. NASA has been forbidden to maintain an adjunct ELV program and directed to procure launch services commercially or through the USAF for all civilian ELV mission requirements. The fledgling U.S. commercial ELV industry is entering the international market with a variety of launch services. Domestic small entrepreneurial ELV providers can be divided into two groups--those who have a small ELV in hardware development for a customer and those companies that are in varying stages of conceptual design without a firm orbital customer. A brief description of both types of emerging small ELV providers is summarized below by vehicle.

U.S. Vehicles: In Development

PEGASUS

Pegasus is a new launch vehicle being developed under a privately funded joint venture by Orbital Sciences Corporation (OSC) and Hercules Aerospace Company. The Pegasus flight vehicle is 49.2 feet long and 50 inches in diameter with a gross vehicle weight of 41,000 pounds. Pegasus, a three-stage, solid propellant, inertially-guided, all composite winged vehicle is carried aloft by a conventional transport/bomber class aircraft to level flight conditions of approximately 40,000 feet and Mach 0.8. After release from the aircraft and ignition of its first stage motor, the vehicle's autonomous flight control system provides guidance through the required suborbital or orbital trajectory. Pegasus is capable of placing up to 900 pounds into low earth orbit. Spacecraft as large as 72 inches long and 46 inches in diameter can fit within the standard Pegasus payload fairing. This vehicle can accommodate three-axis, gravity gradient or spin stabilized spacecraft or multiple smaller satellites on a single launch. Pegasus is the first all new U.S. launch vehicle design since the 1970's. The first orbital launch is scheduled for fall 1989, under contract with the Defense Advanced Research Project Agency (DARPA). DARPA contracted with OSC in 1988 to procure one firm launch with options for five additional missions. OSC is offering Pegasus commercially at a quoted price of $6.3M for a dedicated launch.

TAURUS

OSC was awarded a contract in July 1989 by DARPA for a demonstration launch of a four-stage, inertially guided 3 axis stabilized solid propellant standard small launch vehicle (SSLV) called Taurus. The Taurus vehicle configuration is derived from Pegasus and Peacekeeper stages. The vehicle is fully transportable allowing for rapid launch site establishment compatible with both Eastern and Western Test Ranges and rapid launch call-up. The overall vehicle length is 90.25 feet with a gross lift-off weight of 180,000 pounds. The Taurus standard payload fairing is 50 inches in diameter and 96 inches long; however, larger fairings are available. Taurus is capable of placing 3,000 pounds into a polar low earth orbit and approximately 830 pounds to a geosynchronous transfer orbit. OSC will offer Taurus launch services commercially with a fixed price launch service cost of $15M and product delivery within 18 months from contract award. The first DARPA demonstration launch is targeted for June 1991. DARPA also has four launch options for future missions under its launch services contract.

U. S. Vehicles: Conceptual Design

INDUSTRIAL LAUNCH VEHICLE

The American Rocket Company (AMROC) is privately financing development of a family of commercial suborbital and orbital launch vehicles to serve the growing international commercial marketplace. A single module suborbital launch vehicle (SLV) will evolve into a standard single module suborbital and later into a three module orbital vehicle (ILV-S) to launch small satellites. The ILV-S will be capable of placing 590 pounds to a polar orbit at a cost of approximately $7.5M. The ILV-I, the largest planned vehicle in the family, is a four-stage vehicle that will be comprised of 22 essentially identical hybrid engine modules. The ILV employs hybrid propulsion technology that draws on fundamental technological research generated by the U.S. Government, but specifically developed by AMROC through applied research and development. The ILV-I will be capable of placing 3000 pounds to a polar orbit at a cost of $12.0M. The payload adapter for the ILV family will be very similar to the Delta/PAM-D/Ariane mounting interface. The ILV-I nose fairing offers a dynamic envelope of 7.5 feet in diameter. The ILV can be launched from either the ETR or WTR. The first suborbital launch of SLV is scheduled for this fall; however, no commercial orbital launches have been consummated at this time.

CONESTOGA

The Conestoga launch vehicle family is an all solid small- to medium-class series of boosters, based on the buildup of Castor IVH solid rocket motors in a strap together configuration. Conestoga is under conceptual design by Space Services, Inc. (SSI) with launch possible from a variety of launch sites (ETR/WTR/Hawaii/Florida). The Conestoga can place payloads of 900-2,200 pounds to a polar orbit and 1,300-5,500 to low earth orbit. SSI successfully launched the first U.S. commercial sounding rocket--the Starfire I on March 29, 1989. SSI is offering the Conestoga on the commercial marketplace for $10-20M for a dedicated launch depending on the specific mission requirements and vehicle configuration. No firm orbital commitments have been made at this time; however, SSI offers delivery 14 to 18 months after contract award.

EPAC S SERIES

E' Prime Aerospace Corporation (EPAC) was formed in 1987 as a private venture commercial space launch service company. The EPAC S Series of ELV's is based on Peacekeeper derived stages, components and techniques. The S Series are modular combinations of four basic components: (1) a Peacekeeper stage 1 derived prime mover; (2) a solid propellant upper stage motor, based on Peacekeeper and small ICBM technology; (3) a liquid propellant post-boost vehicle based on the Peacekeeper stage IV; and (4) one of two basic payload fairings, one derived from the Peacekeeper shroud and one hammerhead configured for larger payloads. The four different launch vehicle configurations are assembled by varying the mix of solid propellant motors, appropriate post-boost vehicle and fairings to accommodate unique mission requirements. The S vehicles are capable of placing 1,200 pounds to a polar orbit at a cost of $25-35M or as much as 20,000 pounds to a low earth orbit via the S-IV at a cost of $70-80M. EPAC plans launch from either ETR or WTR with a first orbital launch of the S-I targeted for 1991. EPAC is offering launch services to the international science and commercial community. No launch commitments have been made at this time.

POSEIDON (C-3)

Lockheed Missiles and Space Company has developed a conceptual design to utilize Poseidon Fleet ballistic missile components, designs and experience to provide small launch vehicle capability from a variety of launch sites. The launch vehicle design is based on modifying the missile with a new payload adapter, a STAR 48B third stage, new guidance and control electronics and a modified nose fairing. The C-3 design is capable of placing approximately 850 pounds to a polar orbit or up to 1200 lbs to a low earth orbit. Lockheed estimates a 2-year schedule from development to launch for the C-3. Cost projections on the proposed modification were not available, nor was a proposed first launch date.

LIBERTY

The Pacific American Launch Services, Inc., (PACAM) has developed the design and hardware of the Liberty 1 system completely through the use of private capital without government support. Liberty is a concept for a single stage to orbit liquid oxygen-hydrogen launch vehicle capable of placing up to 2,200 lbs into a low earth orbit. PACAM targets the defense, commercial and scientific payload community. As currently envisioned, Liberty is approximately 75 feet long and 8 feet in diameter with a nominal gross lift-off weight of 66,000 pounds, of which 60,000 pounds is propellant. Commercial launch operations for the Liberty vehicle are planned to be conducted from a new launch facility to be constructed at Palima Point in Hawaii. However, due to the simplicity of the Liberty launch pad design, pads could be erected for a minimal cost at $5M at either ETR or WTR. The engineering work performed to date on the Liberty supports feasibility of the basic design; however, additional work must be performed before a final design is completed. PACAM offers a launch 21 months after contract award at a cost of $5M per launch for a purchase of three initial launch services. No commercial contracts have been awarded at this time.

A comparison of both existing and developmental/conceptual design domestic small ELV's availability and payload performance capability to a circular low earth and polar orbit is summarized in Table I. Vehicle performance capability to a geosynchronous transfer orbit is also identified where applicable.

Table I
U.S. ELV Payload Performance

U.S. EXPENDABLE LAUNCH VEHICLES CAPABILITIES

VEHICLE		AVAILABILITY	PERFORMANCE (100 NM) LBS		
			LEO (I = 28°)	GTO (I = 28°)	LEO / POLAR (I = 90°)
LTV	SCOUT I	Since 1960's	570	–	460
	SCOUT II	Early 1990's	1,100	–	920
GENERAL DYNAMICS	ATLAS E	Thru 1992	–	–	1,800
MARTIN MARRIETTA	TITAN II	1988	–	–	4,200
OSC	PEGASUS	1989	1,100	275*	840
	TAURUS (SSLV)	June 1991	3,700	830	3,000
AMROC	ILV-S	Early 1990's	4,000		590
	ILV-I				3,000
SSI	CONESTOGA II	14 Months From ATP	1,300	N/A	900
	CONESTOGA III		2,200	N/A	–
	CONESTOGA IV		3,200	N/A	2,200
	CONESTOGA V		5,500	2,700	–
EPAC	S-I	1991	2,500	975	1,200**
	S-II	1992	6,600	2,400	4,500
	S-III	1993	15,800	5,800	9,040
	S-IV	1993	20,300	7,850	12,520
LOCKHEED MISSILES	POSEIDON C3	TBD	1,200	N/A	850
PACIFIC AMERICAN	LIBERTY 1A	21 Months After Funding	490	N/A	380
	LIBERTY 1B		2,200		1,530

* USES SPACECRAFT PROPULSION FOR PERIGEE ASSIST AND APOGEE MANEUVERS
** 300 NM

The previous section identified the range of vehicle capabilities being proposed for use through the 1990's and beyond. However, each vehicle should be considered from a total launch system perspective--with an understanding of both the hardware's performance capability and the attendant operational launch constraints. A few of the more critical constraints have been summarized in Table II for all of the aforementioned domestic ELV's. Launch pad location and availability have a direct impact on the performance capability achievable by a specific vehicle to accomplish unique mission objectives. The LTV/Scout, for example, can be launched from three existing launch sites into a variety of orbits at a rate of 10-12 launches per year. The OSC/Pegasus has unlimited launch site opportunities, since it begins its flight on an aircraft, and can also accommodate twelve missions a year to a range of orbits. The Atlas-E and Titan II are not available commercially and can only be launched into a polar orbit at VAFB. Available launch azimuths dictate the range of orbits a vehicle can perform, with or without dog-leg maneuvers. The payload fairing diameter dictates the physical payload size that each vehicle is designed to accommodate. Individual vehicle users' manuals should be consulted to compare other critical environmental constraints (e.g., acoustics, loads). Launch site location is a factor that also requires consideration since campaign costs associated with launches from international sites can pose a financial burden on small payload operators.

Table II
U.S. ELV Launch Constraints

VEHICLE		LAUNCH PADS	PAD AVAIL.	LAUNCH RATE	LAUNCH AZIMUTH	PAYLOAD FAIRING DIAMETER
LTV	SCOUT I / II	WFF (1 PAD) WTR (SLC-5) SMR (1 PAD)	NOW NOW NOW	10-12 / Year	85-109 / 126-129° 164 - 287° 80 - 130°	2.9 and 3.5 ft
GENERAL DYNAMICS	ATLAS-E	WTR (SLC-3W)	Thru 1992	–	158 - 301°	7 ft
MARTIN MARIETTA	TITAN II	WTR (SLC-4W)	1988	3 / Year	158 - 301°	10 ft
OSC	PEGASUS TAURUS	Carrier Aircraft Concrete Pad - Only	Existing Existing or New (91)	12 / Year 12 / Year	Unlimited ETR / WTR	50" 58" - 80"
AMROC	ILV-S ILV-I	WTR / ETR	When Required	–	WTR WTR	4 ft 7.5 ft
SSI	CONESTOGA	WFF WTR Florida / Hawaii	When Required	72 / Year With Existing Prod. Base	38° - 60° Polar 28° - 60° 17° - Polar	57" I.D. x 123" 190 ft.[3]
EPAC	I / II / III / IV	ETR LC-37 WTR SLC-2E	1992 1991	6 6	57-112° 155-285°	7.6 and 10 ft.
LOCKHEED MISSILES	POSEIDON C3	ETR WTR	When Required	–	Variable	5 ft
PACIFIC AMERICAN	LIBERTY	Hawaii ETR / WTR	3 Q 1991	12 / Year	90° - 180° Inclusive	96"

Reducing the cost of transporting payloads to orbit has been an elusive but much touted goal of every proposed launch system since the early Space Shuttle days as a necessity to develop commercial space goods and services. The DOD/NASA Advanced Launch System Program is focused on reducing both hardware and launch operations costs to achieve a significant savings in the pound to orbit equation.

The cost quoted by a commercial launch service supplier may not always include all of the components of cost associated with launch of a payload into a specified orbit. A brief breakout of the major components of cost include the following:

- Launch Service (vehicle/range services/spacecraft processing)
- Mission Unique Vehicle Modifications
- Insurance Costs: Third Party Liability
  Damage to Government Property
  Reflight Insurance

In addition, some large commercial spacecraft manufacturers make launch reservations on more than one vehicle to provide schedule insurance, should one of the vehicles experience a failure or become unable to provide a launch as requested by the customer. This option is probably too costly for most small payload customers to consider. As mentioned earlier, the launch campaign costs associated with launch from an international launch site (Australia/San Marco/China) may in some cases pose an additional financial burden on the small payload customer. A comparison of the quoted launch service price of the various domestic launch service providers is provided in Table III. The cost per pound to orbit has been calculated for each vehicle assuming launch into a polar orbit. It is important to note that, although the Scout vehicle has the highest cost/pound ratio, it also is the only vehicle which will be available commercially that has a demonstrated and impressive flight history. In addition, the cost/pound ratio is somewhat misleading, since many of the proposed small ELV's offer a payload to orbit capability that may be much higher than that which is required by the small payloads. The cost/pound ratio jumps dramatically if one buys a vehicle with a 3,000 pound performance capability to launch a 500 pound spacecraft. Although there are high hopes by all in the aerospace community that the cost to space can be reduced, the prices quoted for most of the vehicles identified are not based on experience and should be evaluated in a realistic context.

Table III
Domestic ELV Cost Per Pound to Orbit

SMALL ELV COMMERCIAL LAUNCH COSTS
COST PER POUND TO ORBIT ($89)

	QUOTED PRICE ($M)	PAYLOAD TO POLAR ORBIT (LBS)	COST / POUND TO ORBIT ($)
SCOUT	10 - 12	460	21,739 - 26,090
SCOUT II	15	920	16,304
ATLAS E	N/A	1,800	N/A
TITAN II	N/A	4,200	N/A
PEGASUS	6.3	840	7,500
TAURUS	15.0	3,000	5,000
ILV-S	7.5	590	12,712
ILV-I	12.0	3,000	4,000
CONESTOGA II thru V	10 - 20	900 -2,200	9,090 - 11,110
EPAC S-I	25 - 35	1,200	20,830 - 29,170
S-II	20 - 40	4,500	4,440 - 8,890
S-III	50 - 60	9,040	5,530 - 6,640
S-IV	70 - 80	12,520	5,600 - 6,400
POSEIDON C3	TBD	850	TBD
LIBERTY	5.0*	400 - 1,530	12,500

* BUY OF THREE

Alternatives To Small ELV's

The current commercial launch market is so competitive that the small domestic ELV launch service providers compete not just with each other, but also with larger ELV manufacturers, the Space Shuttle, and international small ELV's. This section will briefly address other avenues open to the small payload operator in search of a low cost, timely mode of transport to space.

PIGGYBACKS

In an effort to reduce the cost of access to space and to make use of surplus performance capabilities, larger ELV manufacturers are interested in offering the small payload community the option to fly as a secondary or piggyback payload on those missions where the primary payload does not fully utilize the vehicle's capability. NASA has a history of successfully flying piggyback payloads on the McDonnell Douglas Delta vehicle. General Dynamics (GD) is actively soliciting secondary payloads for launch on their commercial Atlas family of vehicles. GD's marketing survey offers a small satellite of under 1,000 pounds, a low earth orbit option, or a 1,900 pound satellite, a geosynchronous transfer orbit (GTO) option when matched with a primary payload under 4,000 pounds scheduled for launch to GTO. The primary payload schedule and reliability remain unaffected by the companion payload, and the small payload owner is provided a potentially cost-effective alternative to purchase of a dedicated small ELV. GD will make a decision to proceed with offering this service after analysis of the potential market. Ariane is also offering the small satellite operator access to space, as a secondary payload, at a very competitive price. As with GD, the primary payload drives the launch date and mission trajectory.

SPACE SHUTTLE

National space policy directives preclude NASA from providing launch services to commercial communications satellites or other commercial payloads unless they require the Shuttle's unique capabilities or manned intervention. NASA's Office of Commercial Space Programs has established several types of joint arrangements that offer flight time on the Space Shuttle for applied research until the commercial potential of a product has been established.

The most popular arrangements offered by NASA are the Joint Endeavor Agreement (JEA) and the Space Systems Development Agreement (SSDA). The JEA is available for company-sponsored and -directed flight experiments. By offering Shuttle flight time and technical advice, NASA can reduce the cost and risk of product development until the commercial viability of key technologies has been established. NASA also offers a Pre-JEA agreement for organizations that are in the process of defining applied research goals and are not yet ready for the JEA. The SSDA under NASA offers special provisions for launch service, such as deferred payment schedules and exclusivity, to companies developing new systems associated with the development of space hardware infrastructure. Such ventures must have the potential for significant national economic benefits or other worthwhile benefits. The JEA is a no-cost arrangement and therefore very attractive to the small payload community. The reduced Shuttle flight rate, and resultant downtime of the Shuttle fleet after the Challenger accident has resulted in a lengthy queue of commercial payloads awaiting launch.

INTERNATIONAL SMALL ELV'S

The U.S. and U.S.S.R. no longer hold a monopoly on space business. During the past 30 years, many countries have invested in launch sites, pursuing the lucrative commercial market or strengthening their own national defense. International space policies and programs are emerging with developments in commercial and government support and advances in related technologies.

Three major uses for space have evolved over the years--civil, national defense, and commercial. At least twelve different nations have formed government sponsored civilian space organizations dedicated to the peaceful exploration of space. Civil space agencies like NASA, the European Space Agency (ESA), the National Space Development Agency of Japan (NASDA), among others, by changing the way we perceive space, are slowly shifting the emphasis from exploration to productive exploitation.

Some nations are also taking advantage of the defense potential of space. The U.S., Soviet Union, and the People's Republic of China each have military space programs aimed at strengthening their own national defense, whereas other countries use information-gathering and communications satellites for national security purposes. International nongovernment organizations also have a growing interest in space commerce, an area with opportunities in every segment of space industry, from launch services to materials processing and defense systems contracting.

Table IV
International Small ELV's

		AVAILABILITY/ # FLIGHTS	LEO PAYLOAD CAPABILITY (LB)	COMMERCIAL COST
EXISTING VEHICLES				
JAPAN	MU - 3IIS	1971 / 15*	1400 - 1800 (200 NM)	N/A
CHINA	LONG MARCH I	1970 / 2	660 (440 Km)	TBN
INDIA	SLV	1980 / 5	80	N/A
	ASLV	1988 / 2**	330	N/A
	PSLV	1990	2,200	N/A
	GSLV	1994	4,400 (GTO)	N/A
VEHICLES IN DEVELOPMENT / CONCEPTUAL DESIGN				
USSR	START	1991	300	$4-5M ($10,000 - $16,000 / LB)
BRAZIL	VLS	EARLY 1990's	350 (410 NM)	TBN
SWEDEN/ FRANCE	MARIANE	EARLY 1990's	4,000 (POLAR)	TBD

*FLIGHT FAILURES: 1**
*2***

Table IV provides a summary of the availability, performance capability, and costs quoted for commercial use of international ELV's. At this time only the USSR/START has quoted a potential commercial price for launch services. Domestic payload operators considering launch on a nonmarket vehicle must take into account technology transfer and trade constraints, which currently preclude launch of U.S. developed technology without a State Department export license.

ESA/SWEDEN: MARIANE COOPERATIVE VEHICLE DEVELOPMENT

ESA programs include scientific, earth observation and telecommunications satellite development; planetary and astrological research; launch and space vehicle development; and space station research and development. ESA is currently developing a reusable Shuttle-like space vehicle called Hermes, for use during the late 1990's. The Ariane family of launch vehicles is marketed by Arianespace, a commercial spinoff of ESA established to accommodate ESA's launch requirements. Sweden is analyzing the market demand for a small launch vehicle capable of lifting some 4,000 pounds to a polar low earth orbit. The conceptual vehicle, named Mariane, would be developed by ESA utilizing Ariane components, marketed by Arianespace, and launched from Sweden. Interest in this joint venture may dissipate with Arianespace negotiations with Orbital Sciences Corporation to market the Pegasus launch vehicle internationally.

SOVIET: SL-8 AND START VEHICLE DEVELOPMENT

The Soviet space program called Glavcosmos has been most aggressive. The Soviets today are making serious efforts to internationalize their space programs. Glavcosmos has been increasingly successful in marketing Soviet launch, remote sensing and research capabilities to foreign investors. The Proton family of vehicles has developed an excellent reliability record, although they still rely on technology of the past. The smallest Soviet launch vehicle, the SL-8 (C-class) continues to support lightweight, low altitude satellite systems. Although the vehicle is capable of placing a 3,740-pound satellite into a very low earth orbit, the majority of SL-8 payloads (communications and navigation satellites) are less than 2,200 pounds and are placed into much higher circular orbits. The C-class launch vehicle is the second most used class of Soviet booster with a total of nearly 350 missions (through 1987) since its debut in 1964. This class of vehicles is not being offered commercially. The Tsyklon, the Soviet's smallest booster being offered commercially at a cost of $10M, has a performance capability of 8,800 pounds to low earth orbit--outside the range of the small class of vehicles. Space Commerce Corporation/US and Technopribor/USSR have recently entered into an agreement to jointly develop and market a new mobile commercial launch vehicle named Start. Start, a three-stage solid fuel launcher derived from the Soviet SS-20 medium range nuclear missile, will be designed to lift a 300 pound payload into a 310 nmi low earth orbit. The booster will be mounted on a mobile transporter/ launcher which will provide flexibility in launch sites. Initial price quotes claim the vehicle could be offered on a commercial basis for $4-5M per launch to support scientific research or commercial missions including materials processing payloads. The team boasts an ability to produce 300 launchers over a five-year period once the program is initiated. Flight testing could begin as early as 1991, with some ten test launches at various international locations, including Australia, Brazil and possibly the United States anticipated.

JAPAN: MU FAMILY

NASDA is responsible for the engineering and application of technologies into launch and space vehicles, including the new H-II launch vehicle and the HOPE shuttle craft. NASDA is also involved in the international space station project, materials processing, and communications and remote sensing satellite production. The Institute of Space and Astronautical Science (ISAS) is a national interuniversity research institute which is under the Japanese Ministry of Education. ISAS is responsible for research in space science conducted by balloons, sounding rockets, and scientific satellites as well as developing balloons, sounding rockets, the M (Mu) family of small launch vehicles and scientific satellites. Since its first launch in 1971, the Mu launch vehicle has played an important role as an economical launcher with high reliability. Fourteen of the vehicle's 15 flights from the Kagoshima Space Center, which lies on the eastern coast of the Ohsumi Peninsula, have been successfully launched. The standard M-3SII launch vehicle is a solid propellant, three stage booster capable of placing nearly 1,800 pounds into a 200 nmi low earth orbit. The original booster, the M-4S, was four staged and utilized tail wings and spinning for attitude stablization The second generation, M-3C, was a three stage vehicle with augmented second and third stages. A thrust vector control system and side-jet system were applied to the second stage, resulting in a marked improvement of orbit insertion accuracy. The first stage was lengthened and payload capability took a big jump forward in the third generation with the M-3H. The fourth generation M-3S introduced thrust vector control into the first stage to guarantee better accuracy for orbit injection. The current configuration M-3SII has had five succesful flights with its augmented strap-on boosters. Two launches of this configuration are scheduled for 1989. The Japanese have no plans to offer the M-3SII commercially.

CHINA: LONG MARCH I

The Chinese are aggressively moving to become major competitors in the launch service industry. Having reached advanced levels in rocket, launch, and tracking technologies, the state-owned Great Wall Industrial Corporation now offers launch capabilities to foreign customers at competitive rates. In 1965, China began design of a space program and research into the development and launch of Chinese satellites. After five years of effort, the first Chinese satellite SKW-1 was successfully launched into an elliptical orbit by a three-stage launch vehicle--the CZ-1. The CZ-1 uses liquid propellants in the first and second stages and has a solid propellant third stage. CZ-1 is capable of placing a 660 pound spacecraft into low earth orbit. The vehicle has an overall length of 29.45 meters, a diameter of 2.25 meters and a lift-off mass of 81.6 tons. Both launches of the CZ-1 (1970/1971) from the Jiuquan launch site in the Gansu province in northwest China were successful. China has a new version of the rocket under development, the CZ-1C, which, with a liquid instead of solid third stage, will be capable of placing over 800 pounds into low earth orbit. Yet another variant under consideration by the Chinese to target capture of the U.S. Scout market is the CZ-1M, utilizing various third stages added to the basic booster and providing increased performance. Although the Chinese have discussed various new configurations of the CZ-1, there have been no launches of the vehicle since 1971.

INDIA: THE SLV FAMILY

Based on their desire to achieve self-reliance in rocket launching capability, the Indian Space Research Organization (ISRO) initiated development of the SLV-3 in the 1970's. In 1980 with their first successful launch of the SLV-3, India became the sixth country in the world to achieve its own satellite launch capability. The SLV-3, capable of placing approximately 80 pounds into a low earth orbit, has successfully launched five Rohini satellites through 1987. An augmented SLV (ASLV) with strap-on boosters capable of placing 330 pounds into low earth orbit has failed on both of its initial launch attempts. A third launch attempt is targeted for late 1990. A PSLV development acitivity has gone on in parallel and targets launch of a 2,200-pound spacecraft into polar sun-synchronous orbit in 1990. The PSLV weighs 275 tons, is 44 meters high and employs a solid booster of 125 tons for its first stage with six solid strap-ons, a liquid engine second stage, and solid third stage, and a liquid fourth stage. The Indians look to the PSLV to become their workhorse launcher for remote sensing satellites. A future development of a Geostationary Launch Vehicle (GSLV), targeted for launch in 1994, is based on enhancing the capability of the PSLV with the addition of cryogenic engines and provides capability to launch INSAT II class spacecraft into a GTO. India has not announced any plans to offer their SLV's commercially.

BRAZIL/CHINA: VEICULO LANCADOR DE SATELITES (VLS)

Brazil's space agency, Instituto de Pesquisas Espacias (INPE), originally planned to develop a small launcher for domestic use only; however, earlier this summer Brazil's Avibras Aerospacial and the China Great Wall Industry Company formed a joint venture combining communication satellite launching, tracking and networking. The joint venture company, International Satellite Communications, Inc., (INSCOM) will combine the Chinese launch vehicle experience with Avibras space tracking, international marketing and management expertise. The VLS will not compete with the Long March, but is envisioned as a competitor of the U.S. Scout. The VLS is a four-stage solid propellant vehicle capable of placing 350 pounds into a low earth orbit with the flexibility to launch from various launch sites, such as the Chinese Xichang and Jiquan launch sites or the Brazilian site at Alcantara. First launch is targeted for the early 1990's.

A complex international infrastructure has emerged to support the myriad of space activities of the future. National space organizations like NASA, ESA, Glavcosmos, and NASDA are providing the basis for a permanent human presence in space in tandem with exploration into the solar system. As the commercial space market grows, application of advanced technologies will spur even greater commercial utilization of space. It is a continuation of these ambitious programs, from the civil, military, and commercial sectors that will provide assured growth of the space industry and assured access to space.

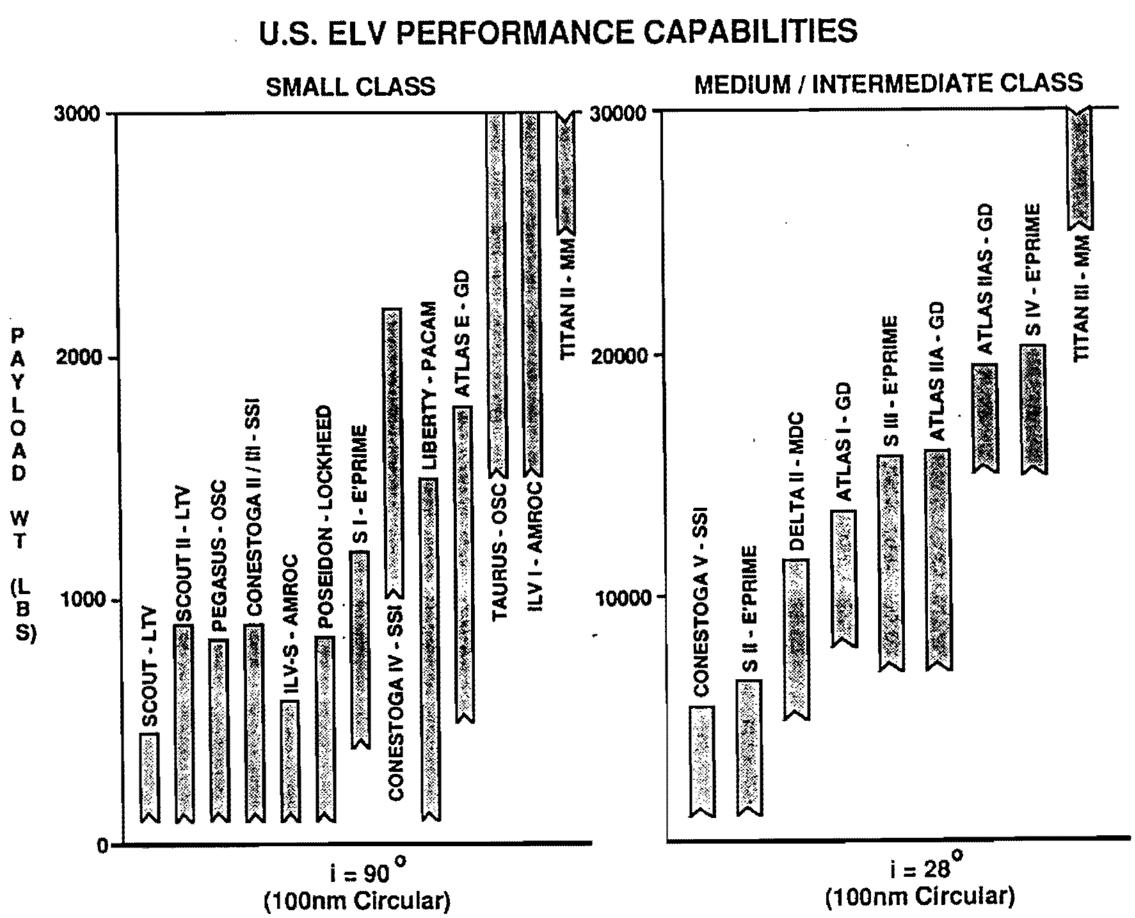
The U.S. role in the future is heavily dependent on budgetary outlays. If the civil space program is not provided necessary funding to pursue the technologies requisite for expansion, we will lose a major technological edge. Reliable, cost-effective ELV's are one important and necessary step to springboard the U.S. into a position of leadership in space.

Market Considerations

The commercial space industry is relatively young. Although the U.S. and foreign governments have been launching space vehicles for the last 30 years, it is only within the last decade that anyone has seriously investigated the cost of space launch activities from the standpoint of economic viability. In most industries, it is possible to project future markets based on historical and current information. In the space launch business, especially the small ELV market, the historical launch history data is predicated for the most part on the government's desire to accomplish specific civil government or national security objectives.

There are currently at least thirteen different vehicles being proposed in the U.S. alone to serve the launch requirements of the under 3,000 pounds to low earth orbit market. Of the thirteen, two vehicles (Atlas-E/F/Titan II) will not be available commercially; one vehicle (Scout) has a demonstrated flight record; two vehicles (Pegasus and Taurus) have a firm contract for a launch by 1991; and the remaining eight are under conceptual design without a launch commitment. Table V compares the payload capability of domestic launch providers all offering services to the small payload community.

Table V
Comparison of U.S. ELV Payload Capability



Estimates for future demand of launch services, both domestic and international, are both limited, and possibly overly optimistic. Based on a review of existing market projections, most notably Battelle's Outside User's Payload Model; Spaceport Florida's Feasibility Analysis, and the Department of Commerce, Space Commerce Industry Assessment--there is either a large or small demand for small ELV's in the commercial space sector. NASA's Office of Commercial Programs will be releasing a study later this year that describes a more sobering projection of the small ELV market of the 1990's. In brief, the small ELV payload market is characterized as requiring government funding for both payload development and launch. The primary commercial payload candidates remain communications satellites, material processing payloads, and industrial scientific experiments.

The U.S. Government market can be characterized as NASA's Small Explorer series of scientific missions (two/year through late 1990's); DARPA's Pegasus/Taurus missions (three funded/eight unfunded/uncommitted options); the USAF Space Test Program (one/year funding uncertain); the NOAA TIROS Weather Satellites (one/year on Atlas-E/Titan II); and the DMSP satellites (one/year on Titan II). Although it is likely new requirements may emerge in the mid-1990's , at this time current budget requirements support a rather modest government demand for small ELV's through the mid-1990's.

Considerations For Launch Vehicle Selection

The launch opportunities for the small payload owner might seem unlimited when one considers all the alternatives: domestic and international small ELV's; piggyback on a larger domestic/international ELV; or negotiating a JEA for a "free-ride" on the Space Shuttle. However, once the payload owner assesses the unique requirements of the individual spacecraft against the capabilities, costs, and constraints of each of the potential launch service providers, the field of realistic space transportation options will often narrow down to a very few vehicles for the unique mission under consideration.

A spacecraft owner needs to critique each launch vehicle option against the following considerations prior to making a launch vehicle selection decision. The most important consideration, being the **spacecraft value** and an assessment of the profit potential and the costs associated with it's replacement. Is a reflight option included in the proposed launch service package under consideration? How many payloads will be launched? Is this a one-of-a-kind spacecraft, or a low-cost series of identical payloads? A second consideration should be the potential launch **vehicle's reliability** record or flight history. A series of low-cost payloads may be willing to take the risk of a new lower-cost launch vehicle with an unproven record. A third factor in the selection process is an assessment of **launch service cost** when compared to the anticipated commercial return on investment; value of the payload at risk, and the associated vehicle reliability record. **Schedule certainty** is important to most payload owners with a commercial product in mind, but may be of less importance to a scientific industrial experiment where time is not a primary driver. **Corporate stability** and long-term viability of the launch vehicle manufacturer is a critical factor all customers would be advised to consider. Once a commitment is made to a particular vehicle, the spacecraft will typically require some modification if it is necessary to be launched on a different vehicle than the one it was designed and manufactured to fit. The ease of **payload/launch vehicle interface** minimizes design/structural changes a payload may have to undergo to be compatible with a particular launch vehicle. The insurance requirements of a given launch vehicle and the insurance package included in the launch service price should be closely examined. Although insurance costs for most small ELV's are significantly lower than those attributable to larger ELV's, the total launch service costs can fluctuate widely between vehicle manufacturers based upon the insurance package each has negotiated. As noted earlier, any customer looking to launch a payload with U.S. component technology on an international ELV would be wise to consider the applicability of technology transfer export regulations.

At present, the State Department will review applications to allow U.S. payloads to launch on Chinese launch vehicles on a case-by-case basis. However, exports of U.S. technology are not allowed to the Soviet Union. A new trend in the larger commercial communication satellite market has been purchase of a satellite on-orbit. A satellite operator in effect buys both a spacecraft and a launch in a package and takes ownership on-orbit. It is not likely that such an option would be viable with the nascent small communications satellite market, but may be a factor in the future. A final consideration, is a dedicated flight required or will launch as a secondary or piggyback payload meet the mission's requirements? The aforementioned series of considerations, although not necessarily an exclusive list, should be prioritized by each small payload operator prior to committing to a final launch vehicle selection.

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