Commercial Space Transportation

QUARTERLY LAUNCH REPORT

Featuring the launch results from the 4th quarter 2001 and forecasts for the 1st and 2nd quarters 2002

Quarterly Report Topic:

EELV Reliability: Building On Experience

1st Quarter 2002

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Introduction

The First Quarter 2002 Quarterly Launch Report features launch results from the fourth quarter of 2001 (October-December 2001) and launch forecasts for the first quarter of 2002 (January-March 2002) and the second quarter of 2002 (April-June 2002). This report contains information on worldwide commercial, civil, and military orbital space launch events. Projected launches have been identified from open sources, including industry references, company manifests, periodicals, and government sources. Projected launches are subject to change.

This report highlights commercial launch activities, classifying commercial launches as one or more of the following:

- *Internationally competed launch events (i.e., launch opportunities considered available in principle to competitors in the international launch services market)*
- *Any launches licensed by the Office of the Associate Administrator for Commercial Space Transportation of the Federal Aviation Administration under U.S. Code Title 49, Section 701, Subsection 9* (*previously known as the* Commercial Space Launch Act)

Contents

Cover: Vandenberg Air Force Base, Calif., Oct. 18, 2001 - A Delta 2 7320-10 launch vehicle successfully carries the QuickBird imaging satellite into low-Earth orbit for DigitalGlobe. Courtesy of The Boeing Company.

Fourth Quarter 2001 Highlights

EELV Engine Testing Completed

In the fourth quarter of 2001, both Evolved Expendable Launch Vehicle (EELV) engine programs completed ground testing. Boeing's Rocketdyne division completed testing of the new RS-68 engine slated for use on the Delta 4 launch vehicle family, whose first launch is scheduled for July 15, 2002. The 2.9-million-newton (651,000-pound-force) thrust engine has been test fired 183 times for a total of 18,645 seconds of use. Boeing has also completed five hot fire tests of the engine installed in the Delta 4's Common Booster Core stage for a total of 55 seconds.

Firing tests of the RD AMROSS (Pratt & Whitney-NPO Energomash) RD-180 engine were also completed in the fourth quarter with a 350-second burn at at both the 47-percent and 100-percent power levels. The RD-180 is now fully qualified for use on the Atlas 5 Common Core Booster (which is expected to enter service in May 9, 2002). The five-year development of the RD-180 started in November 1996 and involved 135 test firings lasting 25,450 seconds. The engine is also used on Atlas 3, which has made one launch so far.

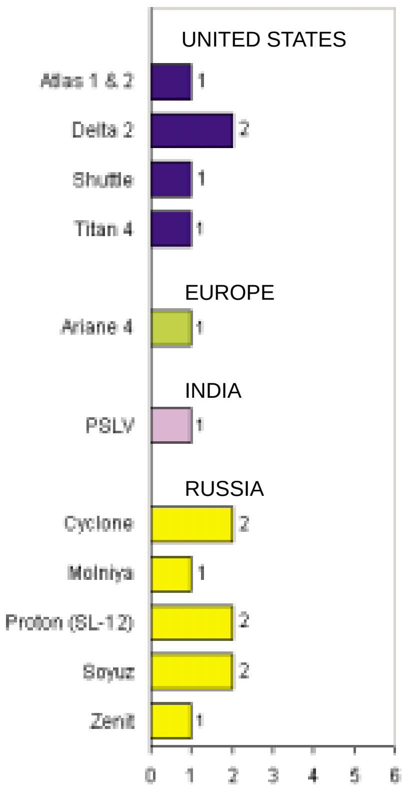
100th Delta 2 Launch

The 100th launch of a Boeing Delta 2 took place on December 7 from Vandenberg Air Force Base in California. The vehicle carried NASA's TIMED and NASA-CNES Jason satellites. TIMED (Thermosphere, Ionosphere, Mesosphere, Energetics and Dynamics) will study a little-known region of Earth's atmosphere, the area between 60 kilometers (37 miles) and 180 kilometers (112 miles) altitude. Jason 1 is a joint U.S.-French oceanographic satellite, which is working together with TOPEX/Poseidon (another U.S.-French satellite launched in 1992) to study the global climate.

Vehicle Use

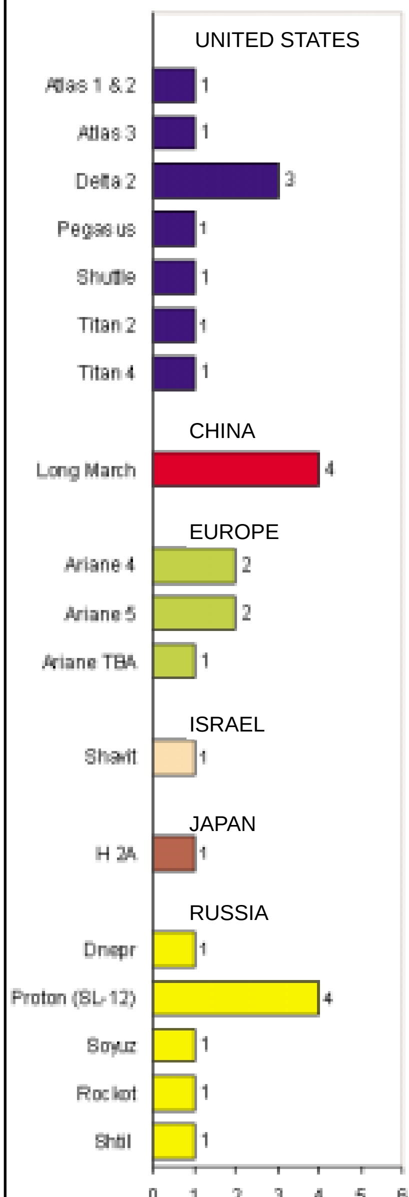
(October 2001 – June 2002)

Figure 1: Fourth Quarter 2001 Total Launch Vehicle Use



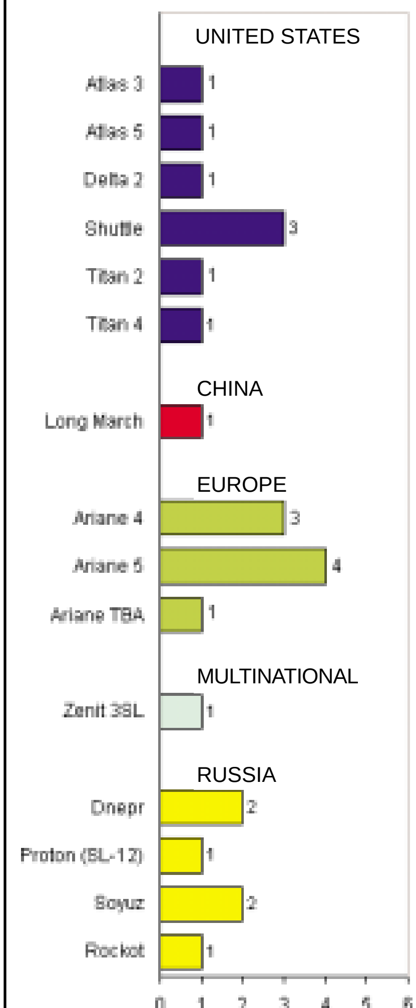
Total = 15

Figure 2: First Quarter 2002 Total Projected Launch Vehicle Use



Total = 28

Figure 3: Second Quarter 2002 Total Projected Launch Vehicle Use



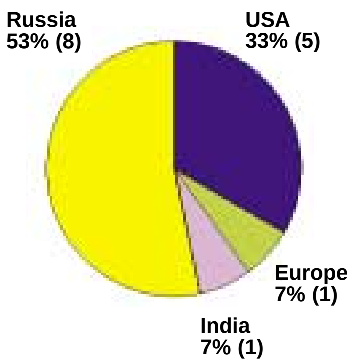
Total = 24

Figures 1-3 show the total number of orbital launches (commercial and government) of each launch vehicle that occurred in the fourth quarter of 2001 and that are projected for the first and second quarters of 2002. These launches are grouped by the country in which the primary vehicle manufacturer is based. Exceptions to this grouping are launches performed by Sea Launch, which are designated as multinational.

Total Launch Events by Country

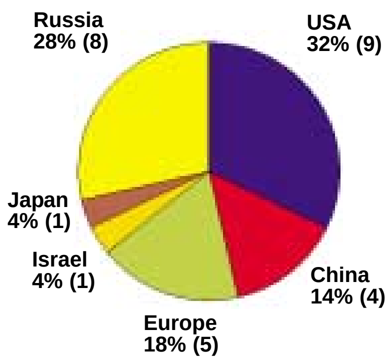
(October 2001 – June 2002)

Figure 4: Fourth Quarter 2001 Total Launch Events by Country



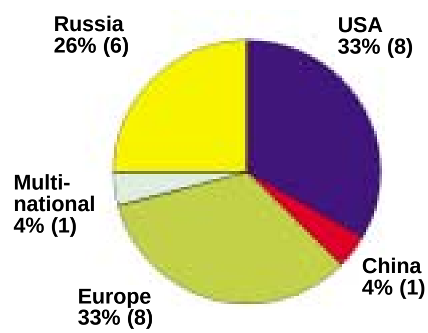
Total = 15

Figure 5: First Quarter 2002 Total Projected Launch Events by Country



Total = 28

Figure 6: Second Quarter 2002 Total Projected Launch Events by Country



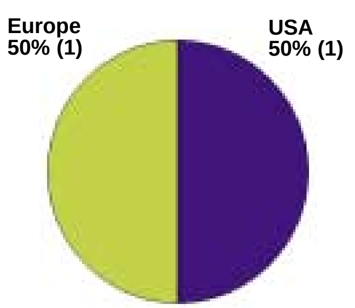
Total = 24

Figures 4-6 show all orbital launch events (commercial and government) that occurred in the fourth quarter of 2001 and that are projected for the first and second quarters of 2002.

Commercial Launch Events by Country

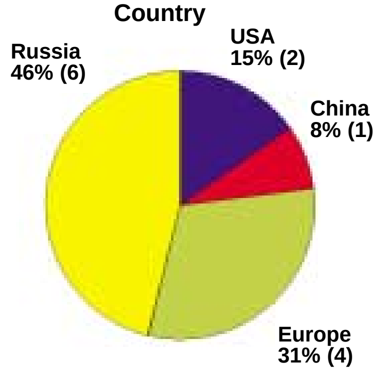
(October 2001 – June 2002)

Figure 7: Fourth Quarter 2001 Commercial Launch Events by Country



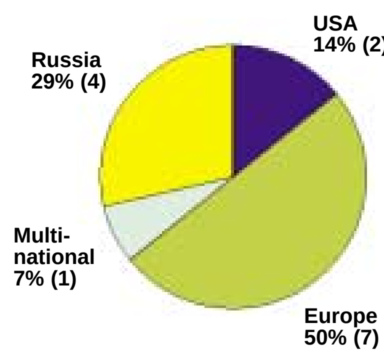
Total = 2

Figure 8: First Quarter 2002 Projected Commercial Launch Events by Country



Total = 13

Figure 9: Second Quarter 2002 Projected Commercial Launch Events by Country



Total = 14

Figures 7-9 show all *commercial* orbital launch events that occurred in the fourth quarter of 2001 and that are projected for the first and second quarters of 2002.

Commercial vs. Non-commercial Launch Events

(October 2001 – June 2002)

Figure 10: Fourth Quarter 2001 2001 Commercial vs. Non-commercial Launch Events

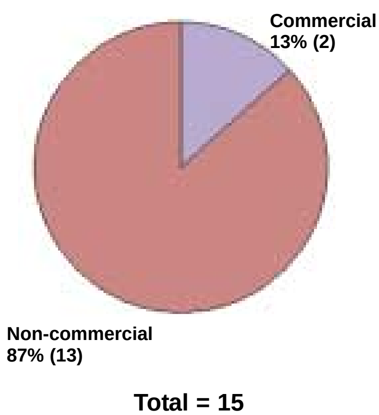


Figure 11: First Quarter 2002 Commercial vs. Non-commercial Projected Launch Events

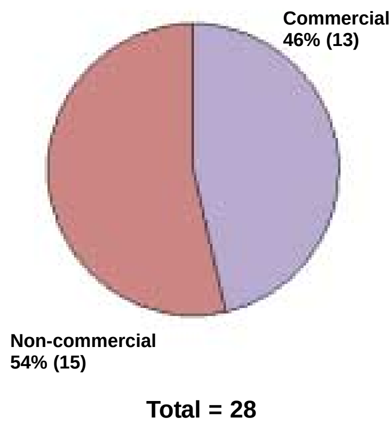
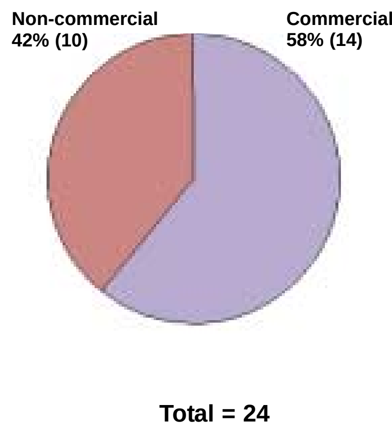


Figure 12: Second Quarter 2002 Commercial vs. Non-commercial Projected Launch Events



Figures 10-12 show commercial vs. non-commercial orbital launch events that occurred in the fourth quarter of 2001 and that are projected for the first and second quarters of 2002.

Fourth Quarter 2001 Launch Successes vs. Failures

(October 2001 – June 2002)

Figure 13: Total Launch Successes vs. Failures

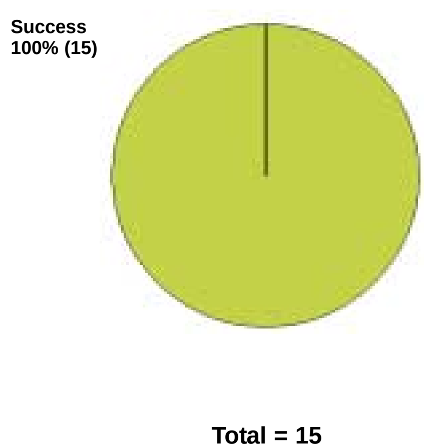


Figure 13 shows successful vs. failed orbital launch events that occurred in the fourth quarter of 2001.

Payload Use

(October 2001 – June 2002)

Figure 14: Fourth Quarter 2001 Payload Use

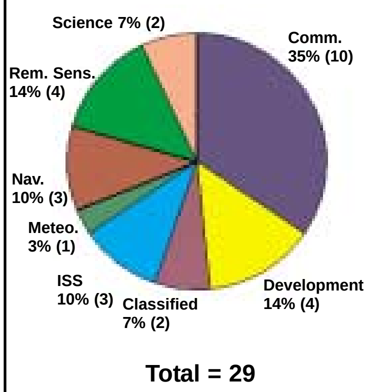


Figure 15: First Quarter 2002 Projected Payload Use

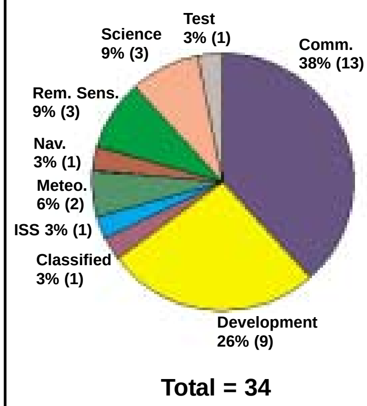
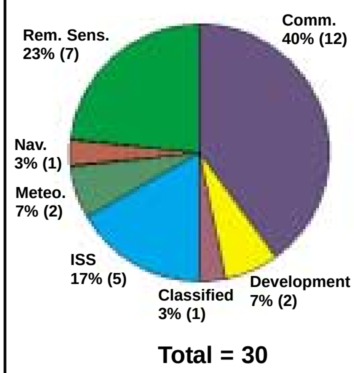


Figure 16: Second Quarter 2002 Projected Payload Use



Figures 14-16 show total payload use (commercial and government), actual for the fourth quarter of 2001 and that are projected for the first and second quarters of 2002. The total number of payloads launched may not equal the total number of launches due to multi-manifesting, i.e., the launching of more than one payload by a single launch vehicle.

Payload Mass Class

(October 2001 – June 2002)

Figure 17: Fourth Quarter 2001 Payload Mass Class

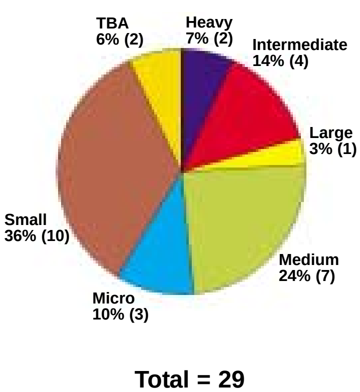


Figure 18: First Quarter 2002 Projected Payload Mass Class

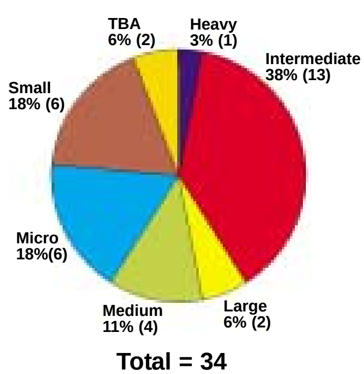
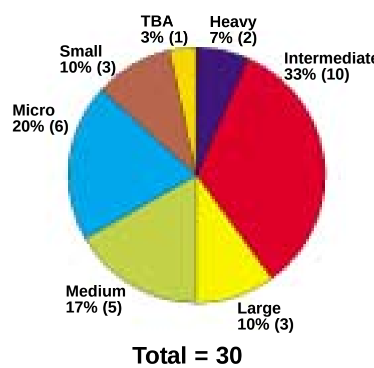


Figure 19: Second Quarter 2002 Projected Payload Mass Class

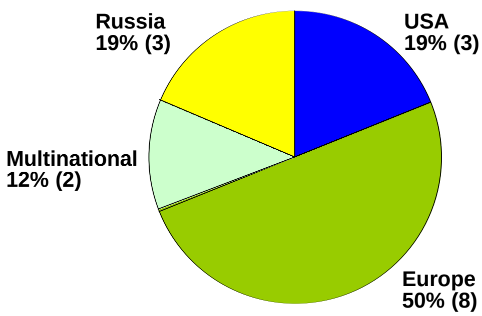


Figures 17-19 show total payloads by mass class (commercial and government), actual for the fourth quarter of 2001 and projected for the first and second quarters of 2002. The total number of payloads launched may not equal the total number of launches due to multi-manifesting, i.e., the launching of more than one payload by a single launch vehicle. Payload mass classes are defined as Micro: 0 to 91 kilograms (0 to 200 lbs.); Small: 92 to 907 kilograms (201 to 2,000 lbs.); Medium: 908 to 2,268 kilograms (2,001 to 5,000 lbs.); Intermediate: 2,269 to 4,536 kilograms (5,001 to 10,000 lbs.); Large: 4,537 to 9,072 kilograms (10,001 to 20,000 lbs.); and Heavy: over 9,073 kilograms (20,000 lbs.).

Commercial Launch Trends

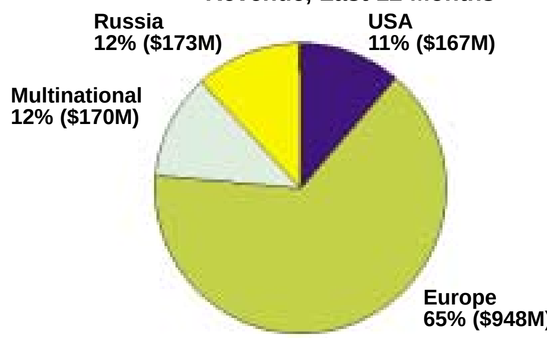
(January 2001 – December 2001)

Figure 20: Commercial Launch Events, Last 12 Months



Total = 16

Figure 21: Commercial Launch Revenue, Last 12 Months



Total = $1458M

Figures 20 shows commercial launch events for the period January 2001 to December 2001 by country.

Figures 21 shows commercial launch revenue for the period January 2001 to December 2001 by country.

Figure 22: Commercial Launch Events by Country, Last Five Years

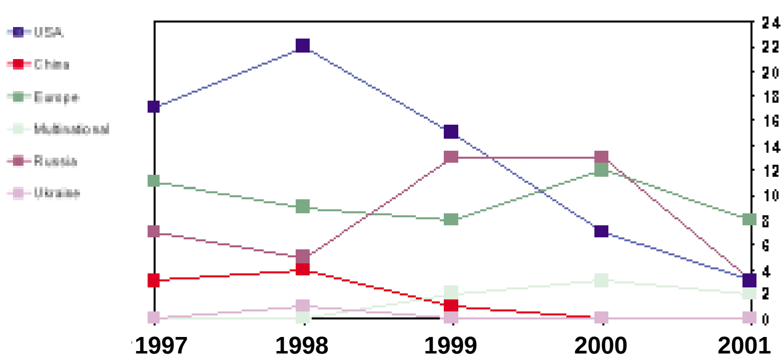


Figure 22 shows commercial launch events by country for the last five full years.

Figure 23: Commercial Launch Revenue (in $ million) by Country, Last Five Years

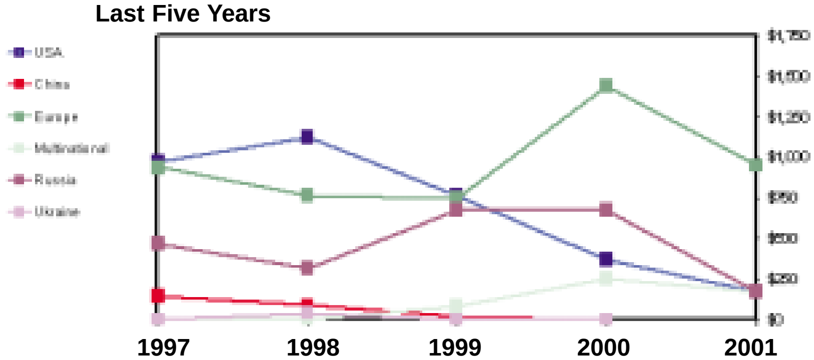


Figure 23 shows commercial launch revenue by country for the last five full years.

EELV Reliability: Building on Experience

The National Space Transportation Policy, signed by President Clinton on August 5, 1994, gave the National Aeronautics and Space Administration (NASA) responsibility for reusable launch vehicle development, while tasking the Department of Defense (DoD) with improving expendable launch vehicles (ELV) and the nation's existing launch infrastructure. This goal resulted in the initiation of the Evolved Expendable Launch Vehicle (EELV) program. Under this program DoD was to partner with industry to develop a national launch capability to satisfy both government and commercial payload requirements and reduce the cost of space access by at least 25 percent. Four companies initially competed for DoD contracts to develop these vehicles and ultimately, Lockheed Martin Corporation and The Boeing Company were awarded EELV production and service contracts for their respective Atlas 5 and Delta 4 vehicles.

With a focus on the Atlas and Delta families, the Fourth Quarter 2001 Quarterly Launch Report special report addressed the process by which launch vehicles become more reliable and capable over time. The present report augments the prior one, examining in greater depth the EELV program's effort to produce highly reliable vehicles in a relatively short period of time. The first part of this report shows that vehicle reliability tends to increase with testing and flight experience, and that later variants within a launch vehicle family tend to be more reliable than earlier ones. The second part of the report describes the approaches, many of which were taken to improve earlier vehicles' reliability that Boeing and Lockheed Martin are now using to bolster reliability and reduce technical risk of their respective EELVs. The report suggests that if past is prologue, the Atlas 5 and Delta 4 EELVs are on track to exceed the initial reliability of their predecessors in the short term, with a good chance of achieving superior reliability over the long term.

LAUNCH VEHICLE RELIABILITY AND THE IMPACT OF EXPERIENCE

Launch vehicles are complex devices, and like any complex device, it takes time to refine them. The ideal way to "wring out" a design's flaws and thus bolster a vehicle's reliability is to follow a thorough testing process. Vehicle developers routinely conduct ground tests of vehicle components and systems before a complete vehicle ever flies. While these tests certainly are critical to increasing a vehicle's chances of flight success, they do not guarantee that a vehicle will fly flawlessly. Optimally, ground tests would be followed by many dedicated test flights of the vehicle carrying a mass simulator or dummy payload. Repeat numbers of test flights would allow vehicle engineers to analyze the vehicle's performance, make modifications to enhance performance, and fly the vehicle to test the performance with design alterations.

For early ballistic missiles, the testing process did involve a large number of flights: the Atlas Intercontinental Ballistic Missile (ICBM), for

Vehicle	Number of Test Flights
Ariane 1	1
Ariane 2	0
Ariane 3	0
Ariane 4	1
Ariane 5	3
Space Shuttle	4
Atlas 1 & 2	0
Delta 3	1
Zenit 3SL	1

Table 1: Numbers of Test Launches for Launch Vehicles

one, made 82 test flights between 1957 and 1962, while the Titan ICBM made around 100 test flights. In contrast to missiles, launch vehicles generally make far fewer test flights (see Table 1). While this, in part, is because many launch vehicles are based on ballistic missiles and benefit from the testing carried out on the missiles, it is also because numerous test flights can be cost- and schedule-prohibitive for vehicle manufacturers. As a result, it is not uncommon for the first flight of a launch vehicle to carry a functional payload, as opposed to a mass simulator or test equipment. Regardless of whether or not a vehicle is formally in test status, however, continuous operations, analysis of performance, and subsequent design improvements are key to raising a design's reliability[1].

Moreover, constant monitoring of vehicle performance is necessary to maintain a high degree of reliability once it has been achieved: even proven systems may lose reliability as a result of changes in manufacturing or operating procedures. For example, both the Pratt and Whitney RL-10 engine, used on the Delta 3 and the Centaur upper stage, and the Proton's NPO Energomash 11D58M have caused launch failures because changes in manufacturing procedures resulted in flawed engines. Once these failures occurred, the problems were identified and corrected, but these cases serve to illustrate that launch vehicles require constant attention to keep them reliable.

THE CASES OF ARIANE, ATLAS, AND PROTON

To explore the development of vehicle reliability over time, this report considers members of three vehicle families: Ariane 1-4, pre-Atlas-3 Atlas vehicles, and pre-Proton-M Proton vehicles (Proton M and Atlas 3 vehicles differ too much from there respective predecessors to make their inclusion meaningful). These vehicles were chosen to compare the development histories of three representative vehicles of major spacefaring nations. Although other vehicles, such as the Delta and Soyuz, also have lengthy development histories, the three vehicles chosen are all similar in mass class and compete for the same basic market.

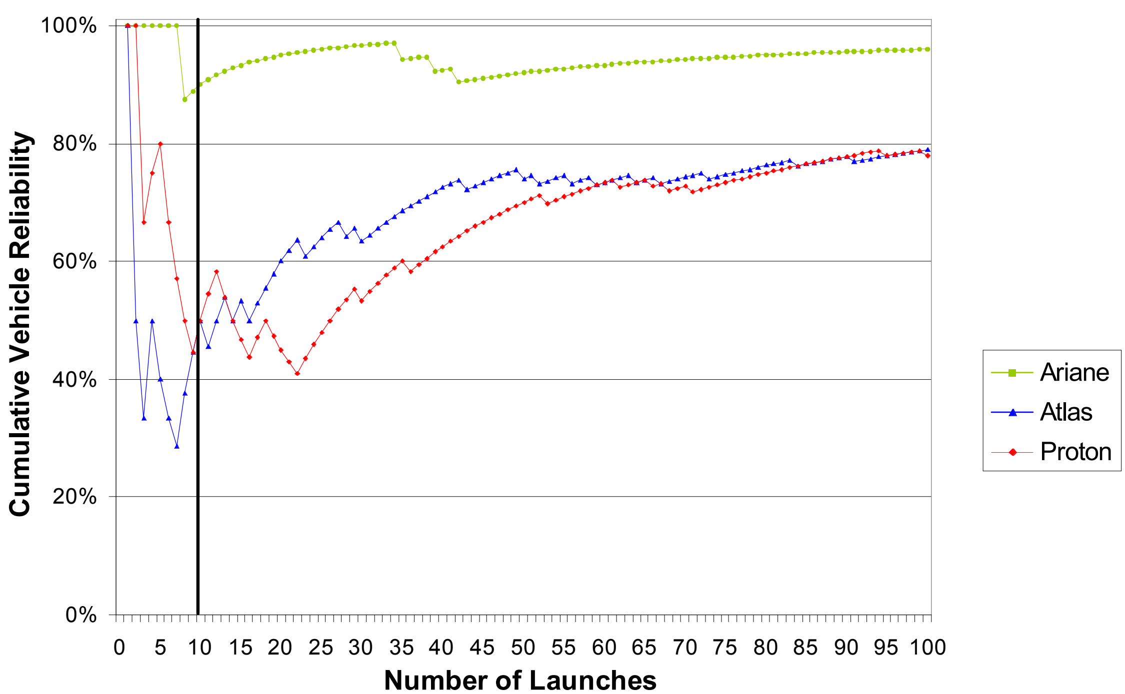


Figure 1: Cumulative Vehicle Reliability for the First 100 Launches

	Ariane 1-4			Atlas			Proton		
	Launch Number	Success Rate (for Interval)	Change	Launch Number	Success Rate (for Interval)	Change	Launch Number	Success Rate (for Interval)	Change
1	1-50	88%	N/A	1-50	74%	N/A	1-50	70%	N/A
2	51-100	94%	6%	51-100	84%	10%	51-100	86%	16%
3	101-136	100%	6%	101-150	88%	4%	101-150	96%	10%
4				151-200	90%	2%	151-200	96%	0%
5				201-250	88%	-2%	201-250	92%	-4%
6				251-300	100%	12%	251-284	94%	2%
7				301-306	100%	0%			

Table 2: Vehicle Reliability by Chronological Intervals of Fifty

As can be seen in Figure 1, a vehicle's first ten launches are generally the most problematic. For both Ariane and Atlas, the worst cumulative reliability occurred during the first ten launches. The Russian Proton deviates from this pattern, having made 22 flights before its reliability began to improve. This late turning point reflects the Russian design methodology, which calls for flight testing earlier in the design process than would be considered appropriate by a Western designer. Despite this testing process, the Proton still begins to improve early in its lifetime. By the 100th launch, Atlas and Proton achieved nearly identical cumulative reliabilities.

In order to portray early reliability gains in a different light, Table 2 and Figure 2 show vehicle success rates by increments of 50. The success rate of each set of 50 launches is based on the experience in that set of launches; it is not cumulative. As such, Table 2 and Figure 2 provide vehicle reliability data for distinct 50-launch increments and illustrate differences in reliability among different periods (for instance, the difference between the reliability of launches 1 through 50 as compared to launches 51 through 100). Note that the size of the final interval varies among the vehicles, as none of them have been launched an even multiple of fifty times.

Table 2 and Figure 2 show that these vehicles continue to improve for at least the first 100 to 150 launches, with reliability reaching the 90- to 100-percent range. As long as a vehicle's reliability is under 100 percent, however, there is the possibility of further improvement. This

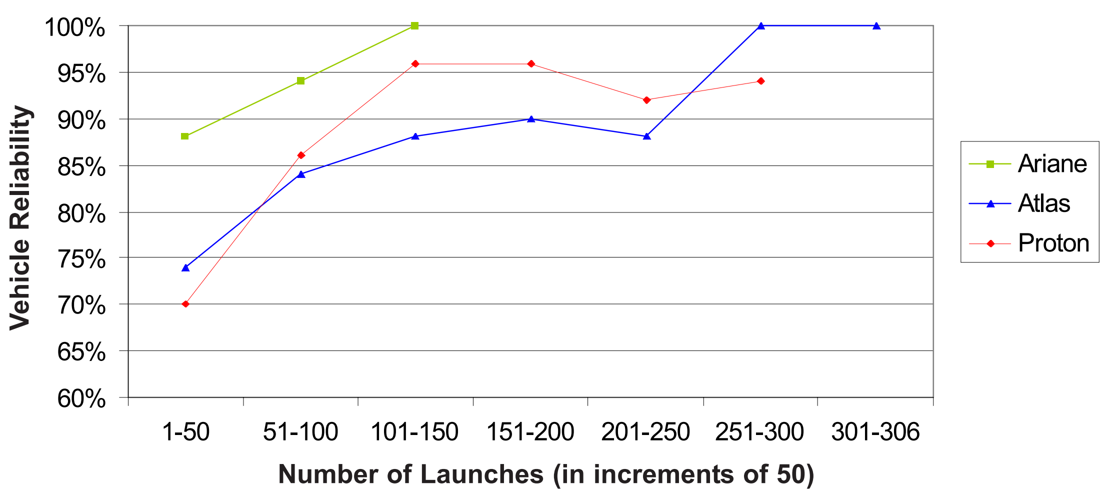


Figure 2: Vehicle Reliability by Chronological Intervals of Fifty

is demonstrated by the improvement shown by the Atlas vehicle in its final two increments (flights 251 through 306).

For Ariane, reliability improvement ceased when it achieved a perfect record in its last interval of 36 launches. This achievement is even more striking considering that the actual number of successful consecutive Ariane launches was 65, from 1995 to the present. As of the first quarter of 2002, Ariane vehicles (excluding the Ariane 5) have cumulative reliability of 94 percent.

Proton improved throughout its first 150 launches, then showed no improvement during its fourth increment and declined by two percent in its fifth increment. The sixth set of launches is promising, returning to the third and fourth increments' 96 percent success rate. Improvement in Proton's reliability already may be occurring, but this will not be clear for another 20 or 30 launches. Proton's lifetime cumulative reliability is 89 percent.

The Atlas reliability development pattern shows similarities to the histories of both Ariane and Proton. Atlas vehicle reliability improved up through the third 50-launch increment, then declined slightly, and then leveled off for the next three periods. In the sixth period, Atlas had a perfect record, which has continued into the first nine launches of the seventh 50-launch period. The total number of consecutive successful launches for Atlas is now 60, for a cumulative reliability of 88 percent.

This analysis intends not to determine which vehicle is superior, but instead to outline the developmental patterns of launch vehicles gained over many launches. Judging from the sample vehicles, it appears that most launch vehicles experience the greatest improvements in reliability over their first 150 launches. Improvement may continue to occur, but the technical innovations resulting in the greatest immediate increases in reliability will have already been made; thus, reliability gains will be harder to achieve.

There is also the possibility that a vehicle may manifest new problems and suffer a decrease in reliability as it ages. In some cases, this occurs because components become obsolete or unavailable, forcing changes in a vehicle that may cause failures. In other cases, design or manufacturing changes in proven components and systems may result in new bugs to replace the old ones that had been carefully removed from the launch vehicle system. Still, even in cases where reliability does decline, the vehicle's reliability remains better than during its initial period of operation: single or even multiple, failures later in a vehicle's life have less of an impact as the number of successful launches grows.

In effect, when launches are successful, reliability improves. When a failure occurs, reliability declines; in correcting the problems revealed by the failure, however, the vehicle becomes more reliable in the long term. Figure 2 shows that both Atlas and Proton have endured declines in reliability. Although it is not possible to go into the details of every launch failure of Ariane, Atlas, and Proton some failures can be chosen for closer examination because they exemplify the process by which launch vehicle reliability improves.

In Proton's last 34 launches, there have been two launch failures (flights 263 and 266). These failures were similar and were caused by the same problem: debris left inside their second-stage engines during assembly at the Voronezh Mechanical Plant in Russia. Design changes have been made in current production engines, and controls have been developed to prevent such problems in the future. These controls include better quality control processes during manufacturing and special examinations of all flight motors. Following these changes and increased scrutiny of older engines, there have been no more Proton launch failures.

There have only been three failures of the Atlas launch vehicle since its commercialization following the Challenger disaster. All three of these failures occurred in Atlas' fifth launch increment (launch numbers 236, 246, and 247). These failures are further examples of why even well-proven vehicles fail. Flight numbers 236 and 246 failed when their Centaur upper stages' engines malfunctioned. Investigations of both failures revealed that the Centaur engines could be frozen during a chill-down procedure used prior to liftoff to ensure proper liquid oxygen (LOX) flow. In order to mitigate this flaw in the Atlas vehicle, General Dynamics (who then produced the Atlas launch vehicle) introduced hardware and launch procedure changes that have prevented the recurrence of this problem.

Atlas' flight number 247 was lost because an improperly tightened set-screw caused the vehicle's first stage to produce only two thirds of its nominal thrust. This shortfall caused the payload to be deployed into an improper orbit. Once this problem was identified and it was determined not to be a design or hardware problem, launches quickly resumed. The problem has not recurred.

Even when a failure is not fully understood useful information can be gained from it. In the case of the most recent failure of an Ariane 4 launch vehicle (an Ariane 42P), the vehicle achieved only 70 percent of its nominal third-stage thrust and failed to place its payload into a proper geostationary transfer orbit. The investigating board concluded that insufficient amounts of LOX had reached the turbopump gas generator. Two causes seemed likely. One was a partial blockage of one of the supplier components by a foreign particle or ice; the other was a leak in the LOX feed, possibly due to a bad seal. Simulations indicated that an obstruction was the most likely cause of the accident.

Despite the uncertainty concerning the cause of the failure, the board recommended a series of steps to improve the Ariane 4's reliability. Six of the board's 13 recommendations covered contamination risks, while five related to improved testing and leak prevention, while the final two concerned the study of overall failure options. Even though the exact cause of the failure was not proven, the chances of a similar failure were reduced and the Ariane 4 has since flown without a failure.

The discussion of vehicle reliability thus far has largely revolved around the accumulation of experience with, and a growing understanding of, launch vehicles by their builders and operators. As can be seen in the previous examples, failures occur for many reasons. Some of these are as simple as an inadequately-torqued screw while others can be traced back to the drawing board. The important point is that failures not caused by wholly random events (for instance, a lightning strike) can generally be prevented once the hardware or procedural flaw that caused them is discovered. With each such discovery-many of which are discovered without the loss of a vehicle-the vehicle grows more reliable. The availability of and desire to conserve this knowledge base is why launch vehicle manufacturers prefer to make improvements in an incremental fashion as opposed to creating new systems from scratch.

Because the knowledge gained through the experiences with one variant is imparted in the next, a new variant within a given vehicle family starts higher on the learning curve than an entirely new vehicle. Table 3 shows the development of the Ariane 1-4 family. It can be seen that the earliest two Ariane variants, Ariane 1 and Ariane 3, have the lowest reliability records of all of the variants considered here. These two variants have the lowest initial reliabilities as well as the lowest lifetime reliabilities. Note that both initial and lifetime reliabilities generally increased as new Ariane variants were introduced.

Vehicle Variant	Introduction Year	First Ten Launches			All Launches		
		Success	Failure	Reliability	Success	Failure	Reliability
Ariane 1 (all)	1979	8	2	80%	9	2	82%
Ariane 3 (all)	1984	8	2	80%	9	2	82%
Ariane 2 (all)	1986	5	1	83%	5	1	83%
Ariane 44LP	1988	9	1	90%	25	1	96%
Ariane 44L	1989	9	1	90%	32	1	97%
Ariane 40	1990	7	0	100%	7	0	100%
Ariane 42P	1990	9	1	90%	13	1	93%
Ariane 44P	1991	10	0	100%	17	0	100%
Ariane 42L	1993	9	1	90%	10	1	91%
Totals		74	9		127	9	

Table 3: Ariane 1-4 Variant Launch Reliability

Unfortunately, an analysis of the reliability differences among variants in a family cannot be applied to Proton or Atlas. The major distinction among various Proton vehicles is the upper stage; Proton vehicles do not vary in the same way as Ariane vehicles, whose variants use different combinations of strap-on boosters and were introduced at different times. The large number of Atlas variants, many of which have made only two or three launches, prevents the Atlas from being useful as an example of the effects of variation on launch vehicle reliability. Nonetheless, the analyses in this section suggest that, in general, the most reliable launch vehicle is one whose history is extensive and replete with incremental developments.

EELV RELIABILITY

The products of the EELV program, the Lockheed Martin Atlas 5 and the Boeing Delta 4, represent an effort to create new vehicles that achieve high reliabilities but with fewer launches than the vehicles discussed above. The EELV manufacturers hope their vehicles will not undergo the initial failures of their predecessors and will capture many of the reliability improvements developed during their predecessor's operational lifetimes. The manufacturers hope to achieve high reliability using a combination of their predecessors' heritage and experience, incremental innovation, and simplification of various systems.

Despite embracing quite different design choices, the developers of both the Delta 4 and the Atlas 5 are using the same approach to maintain the experience gained by previous launch vehicles. Both Delta 4 and Atlas 5 have been preceded by intermediate vehicles serving as transitions between them and their proven ancestors. These "bridge" vehicles are the Atlas 3 and the Delta 3, both of which have a large degree of commonality with the older Delta and Atlas designs while pioneering various innovations for the follow-on Delta 4 and Atlas 5.

The Atlas 3 is an initial effort to reduce vehicle complexity while increasing vehicle performance. It uses improved first-stage fuel tank construction and simplified components, while replacing the original Atlas's stage-and-a-half staging concept with a more conventional single stage. It also replaces the original design's three Rocketdyne engines with a single, more powerful, NPO Energomash/Pratt & Whitney RD-180 engine. As a result, the Atlas 3's first-stage thrust section undergoes only one staging event and has only seven fluid interfaces, as opposed to previous Atlas models with six staging events and 17 fluid interfaces.

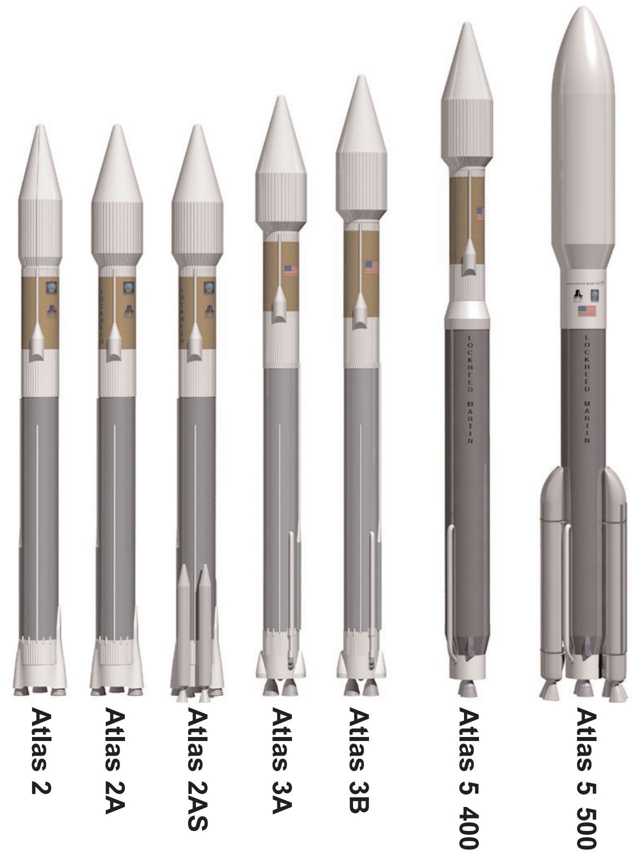


Figure 3: Atlas Vehicle Lineage

The Atlas 3 family also introduces two improved versions of the Centaur upper stage: the Atlas 3A uses a single-engine Centaur, removing one RL10A-4-1 engine and centering the other along the Centaur's axis, while the Atlas 3B uses a lengthened version of the improved Centaur with two RL10A-4-2 engines. The improved Centaur engines include upgrades, such as chiller modifications and a health monitoring system designed to increase reliability and operational standards. Both the single- and dual-engine Centaurs will continue to be used on the Atlas 5 series after the Atlas 3 is retired (see Figure 3 for the Atlas lineage).

Unlike the Atlas 3 program, Boeing did not improve the Delta 3's engines for use on the Delta 4, but it does introduce a number of new features that will be used on the Delta 4. The upper stage introduced on the Delta 3 will be used in an expanded form (using the same RL10B-2 engine as the previous version with larger fuel and oxidizer tanks) on the Delta 4, along with the Redundant Inertial Flight Control Assembly avionics system that debuted on the Delta 3.

By introducing a limited number of new components to the EELVs, and doing so as much as possible through transitional vehicles, Boeing and Lockheed Martin are attempting to increase EELV reliability while reducing their development risk. Lockheed Martin is confident, for instance, that the success of the Atlas 3 has proven 80 percent of Atlas 5's technologies.[2]

In addition to reducing risk and thereby improving reliability by incrementally introducing new systems and better designs, both the Atlas 5 and Delta 4 are designed with

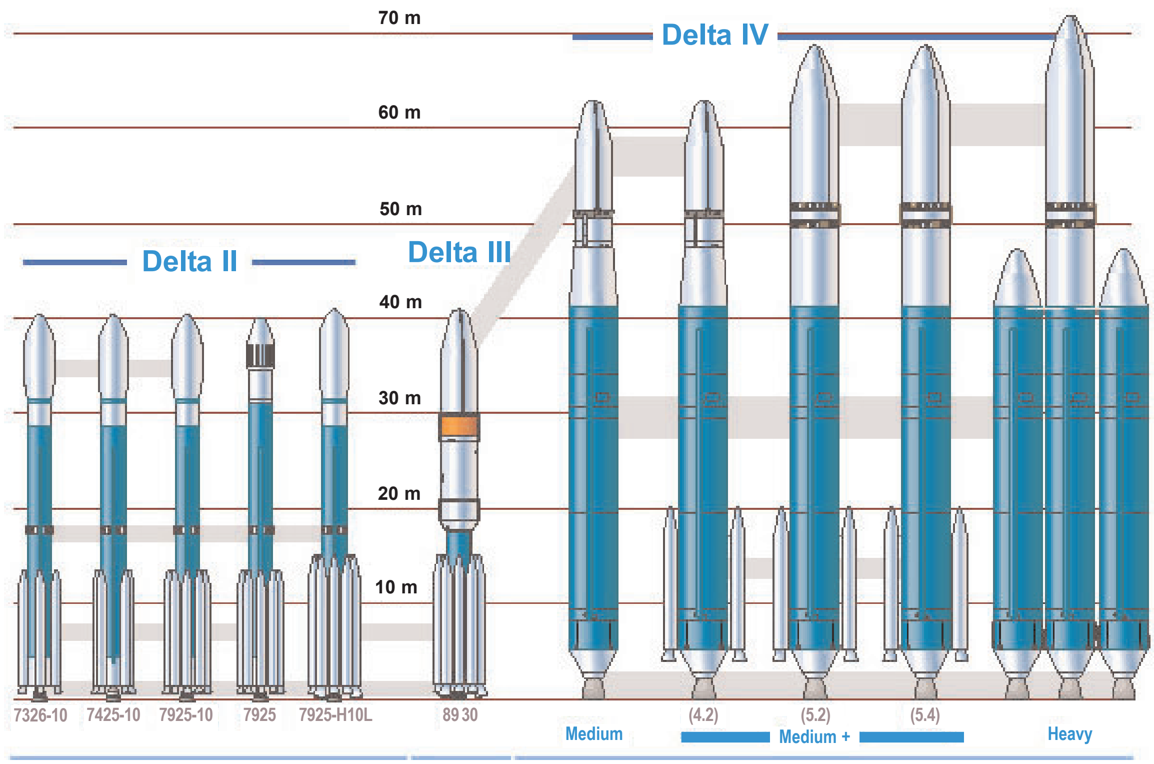


Figure 4: Delta Vehicle Lineage

fewer possible failure modes than their predecessors. The Atlas 5, for example, is estimated to have approximately 125 potential single-point failures as opposed to over 250 for the Atlas 2AS.[3] Lockheed Martin will also replace the pressure-stabilized fuel tanks used on all previous Atlas vehicles with structurally-stable propellant tanks. These tanks will support the weight of the vehicle's payload without being fueled, in contrast to previous Atlas vehicles, which required the pressure of the fuel in their tanks to bear the weight of their payloads. The new Atlas 5 Common Core Booster™ (CCB) will be much more robust than its pressure-stabilized predecessor, while still using many systems proven on the Atlas 3.

The Delta 4 involves further improvements on the components pioneered by the Delta 3. It introduces a new first-stage common booster core (CBC), which will use the Rocketdyne RS-68 engine developed specifically for the Delta 4. This engine has 95 percent fewer parts than the comparable Space Shuttle Main Engine (SSME) and requires only 8,000 hours of touch labor, compared with 171,000 hours for the SSME.[4]

The heavy version of the Delta 4 will use three CBC stages in parallel. It will resemble the current Titan 4 in appearance, but instead of using two entirely different engine systems (a liquid-fueled core stage and strap-on solid fuel boosters) it will have a single design repeated three times. Only after the CBC has been tested in single core launches will it be used in this triplex arrangement-an approach aimed at reducing the risk of vehicle failure (see the Delta vehicle lineage in Figure 4).

CONCLUSION

If the strategies of using incremental innovation and simplified components and systems are successful, the overall reliability of the Boeing and Lockheed Martin EELVs should be higher than that of earlier variants in their respective vehicle lineages at a corresponding point in their development. As the name *Evolved* Expendable Launch Vehicle suggests, these vehicles are intended to build on success and limit new risk, while introducing capabilities equivalent to those of a new vehicle. If experience provides any guidance, to the extent that launch vehicle development is successfully managed, the EELVs will have higher initial reliabilities than those of a clean-slate design. Such a success will improve U.S. launch assets while maintaining current capabilities.

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1 It should be noted that every launch of an expendable launch vehicle (ELV) is actually an inaugural flight of that particular vehicle (if not that particular design). ELV reliability is thus not easily or fairly comparable with that, for example, of a certified commercial aircraft.

2 http://www.ilslaunch.com/missionplanner

3 Ibid.

4 http://lean.mit.edu/Events/workshops/files_public/EBRT_eelv.pdf

Fourth Quarter 2001 Orbital Launch Events

Date		Vehicle	Site		Payload or Mission	Operator	Use	Vehicle Price	L	M
10/5/01		Titan 4B	VAFB		NRO T3	National Reconnaissance Office	Classified	$350-450M	S	S
10/6/01		Proton	Baikonur		Raduga 1-06	Russian Ministry of Defense	Communications	$75-95M	S	S
10/11/01		Atlas 2AS	CCAFS		NRO A2	National Reconnaissance Office	Communications	$90-105M	S	S
10/18/01	√	+ Delta 2 7320	VAFB	*	QuickBird 2	DigitalGlobe	Remote Sensing	$45-55M	S	S
10/21/01		Soyuz	Baikonur		Soyuz ISS 3S	Rosaviakosmos/ NASA	ISS	$30-40M	S	S
10/22/01		PSLV	Sriharikota Range		PROBA	European Space Agency	Development	$15-25M	S	S
					TES	Indian Space Research Organization	Remote Sensing			
					BIRD	Deutschen Zentrum für Luft und Raumfahrt	Development			
10/25/01		Molniya	Plesetsk		Molniya 3-51	Russian Ministry of Defense	Communications	$30-40M	S	S
11/26/01		Soyuz	Baikonur		Progress ISS 6P	Rosaviakosmos/ NASA	ISS	$30-40M	S	S
11/26/01	√	Ariane 44LP	Kourou	*	DirecTV 4S	DirecTV, Inc.	Communications	$90-110M	S	S
12/1/01		Proton	Baikonur		Kosmos 2380	Russian Ministry of Defense	Navigation	$75-95M	S	S
					Kosmos 2381	Russian Ministry of Defense	Navigation			
					Kosmos 2382	Russian Ministry of Defense	Navigation			
12/5/01		Shuttle Endeavour	KSC		STS 108	NASA	Crewed	$300M	S	S
					ISS UF-1	NASA	ISS			
12/7/01		Delta 2 7920	VAFB		Jason 1	NASA/Centre National d'Etudes Spatiales	Remote Sensing	$50-60M	S	S
					TIMED	NASA	Scientific			
12/10/01		Zenit 2	Baikonur		Meteor 3M N1	Rosaviakosmos/NASA	Meteorological	$35-50M	S	S
					Badr 2	Space and Upper Atmosphere Research Commission	Development			
					Kompass	Izmiran	Scientific			
					Maroc-Tubsat	Royal Center for Remote Sensing	Remote Sensing			
					Reflektor	Scientific Research Institute for Precision Device Engineering	Development			
12/21/01		Cyclone 2	Baikonur		Kosmos 2383	Russian Ministry of Defense	Classified	$20-25M	S	S
12/28/01		Cyclone 3	Plesetsk	*	Gonets D1 7	Smolsat (NPO PM, et. al)	Communications	$20-25M	S	S
				*	Gonets D1 8	Smolsat (NPO PM, et. al)	Communications			
				*	Gonets D1 9	Smolsat (NPO PM, et. al)	Communications			
					Kosmos 2384	Russian Ministry of Defense	Communications			
					Kosmos 2385	Russian Ministry of Defense	Communications			
					Kosmos 2386	Russian Ministry of Defense	Communications			

√ Denotes commercial launch, defined as a launch that is internationally competed or FAA licensed.
+ Denotes FAA-licensed launch.
* Denotes a commercial payload, defined as a spacecraft that serves a commercial function or is operated by a commercial entity.
L and M refer to the outcome of the **L**aunch and **M**ission: S = success, P = partial success, F = failure
Note: All launch dates are based on local time at the launch site at the time of launch.

First Quarter 2002 Projected Orbital Launch Events

Date			Vehicle	Site		Payload or Misson	Operator	Use	Vehicle Price
1/15/02			Titan 4B/Centaur	CCAFS		Milstar F5	Department of Defense	Communications	$350-450M
1/23/02	√		Ariane 42L	Kourou	*	Insat 3C	Indian Space Research Organization	Communications	$80-100M
1/XX/02			Shavit 1	Palmachim		Ofeq 5	Israel Space Agency	Classified	$10-15M
1/XX/02			Long March 2F	Jiuquan		Shenzhou 3	China National Space Administration	Development	N/A
2/1/02			Pegasus XL	CCAFS		HESSI	NASA	Scientific	$12-15M
2/3/02			H 2A 202	Tanegashima		MDS 1	National Space Development Agency	Development	$75-95M
						Vehicle Evaluation Payload 3	National Space Development Agency	Test	
						DASH	Institute of Space and Astronautical Science	Development	
2/8/02	√	+	Delta 2 7920	VAFB	*	Iridium MS-12	Iridium Satellite LLC	Communications	$50-60M
2/14/02	√		Ariane 44L	Kourou	*	Intelsat 904	Intelsat	Communications	$100-125M
2/21/02	√	+	Atlas 3B	CCAFS	*	EchoStar 7	EchoStar Satellite Corp.	Communications	$90-105M
2/28/02			Shuttle Columbia	KSC		STS 109	NASA	Crewed	$300M
						Hubble Servicing Mission 3B	NASA	Development	
2/28/02			Soyuz	Baikonur		Progress ISS 7P	Rosaviakosmos/ NASA	ISS	$30-40M
2/XX/02			Titan 2	VAFB		DMSP 5D-3-F16	Department of Defense (USA)	Meteorological	$30-40M
2/XX/02	√		Dnepr 1	Svobodny		Unisat 2	Italian Space Agency	Development	$10-20M
						Tropnet 1	Russia	Development	
						Tropnet 2	Russia	Development	
						Tropnet 3	Russia	Development	
3/1/02			Ariane 5G	Kourou		ENVISAT 1	European Space Agency	Remote Sensing	$150-180M
3/4/02	√		Proton	Baikonur	*	Intelsat 903	Intelsat	Communications	$75-95M
3/5/02	√		Rockot	Plesetsk		GRACE 1	NASA/Deutschen Zentrum für Luft und Raumfahrt	Scientific	$12-15M
						GRACE 2	NASA/GeoForschungs Zentrum	Scientific	
3/6/02			Delta 2 7925-10	CCAFS		Navstar GPS 2R-8	Department of Defense	Navigation	$45-55M
3/8/02			Atlas 2A	CCAFS		TDRS F9	NASA	Communications	$90-105M
3/20/02	√		Shtil	Barents Sea		Cosmos 1 Deployment Test 2	The Planetary Society	Development	$0.1-0.3M
3/24/02			Delta 2 7920	VAFB		Aqua	NASA	Remote Sensing	$50-60M
3/XX/02	√		Ariane 5G	Kourou	*	Insat 3A	Indian Space Research Organization	Communications	$150-180M
3/XX/02			Proton	Baikonur	*	Express A1A	Russian Satellite Communciation Co.	Communications	$75-95M
1Q/2002			Long March 4B	Taiyuan		FSW 18	China	Meterological	$25-35M
1Q/2002	√		Proton	Baikonur	*	EchoStar 8	EchoStar Satellite Corp.	Communications	$75-95M
1Q/2002			Long March 4B	Taiyuan		CBERS/Ziyuan 2	China/Brazil	Remote Sensing	$25-35M
1Q/2002	√		Long March 3A	Xichang	*	Atlantic Bird 1	Eutelsat	Communications	$45-55M
1Q/2002	√		Ariane	Kourou	*	N-Star C	NTT Mobile Communications Network	Communications	N/A
1Q/2002	√		Proton	Baikonur	*	DirecTV 5	DirecTV, Inc.	Communications	$75-95M

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L and M refer to the outcome of the **L**aunch and **M**ission: S = success, P = partial success, F = failure
Note: All launch dates are based on local time at the launch site.

Second Quarter 2002 Projected Orbital Launch Events

Date		Vehicle	Site		Payload or Mission	Operator	Use	Vehicle Price
4/4/2002		Shuttle Atlantis	KSC		STS 110	NASA	Crewed	$300M
					ISS 8A	NASA	ISS	
4/10/2002		Ariane 42P	Kourou		SPOT 5	SPOT Image	Remote Sensing	$65-85M
4/XX/02	√	Ariane TBA	Kourou	*	Stellat 5	France Telecom	Communications	N/A
4/XX/02	√	Dnepr 1	Baikonur		Alsat	Algerian Remote Sensing Council	Remote Sensing	$10-20M
					Kina	Surrey Satellite Technology Ltd.	Remote Sensing	
					DMC 5	Government of Thailand	Remote Sensing	
					NigeriaSat 1	Government of Nigeria	Remote Sensing	
					BNSCSat	Surrey Satellite Technology Ltd.	Remote Sensing	
4/XX/02	√	Ariane 4 TBA	Kourou	*	NSS 7	New Skies Satellites N.V.	Communications	N/A
4/XX/2002		Soyuz	Baikonur		Soyuz ISS 4S	Rosaviakosmos/NASA	Crewed	$30-40M
5/2/2002		Shuttle Endeavour	KSC		STS 111	NASA	Crewed	$300M
					ISS UF-2	NASA	ISS	
5/9/2002	√ +	Atlas 5 300	CCAFS	*	Hot Bird 6	Eutelsat	Communications	$85-110M
5/14/2002		Soyuz	Baikonur		Progress ISS 8P	RKK Energia/NASA	ISS	$30-40M
5/28/2002	√ +	Atlas 3A	CCAFS	*	AsiaSat 4	Asia Satellite Telecommunications Co. (Asiasat)	Communications	$90-105M
5/XX/02	√	Dnepr 1	Baikonur		Yamsat 1	National Space Program Office (NSPO)	Development	$10-20M
5/XX/02	√	Ariane 5G	Kourou	*	eBird 1	Eutelsat	Communications	$150-180M
5/XX/02	√ +	Zenit 3SL	Sea Launch Platform	*	Galaxy 3C	Pan American Satellite Corp.	Communications	$75-95M
6/3/2002		Titan 4B/Centaur	CCAFS		NRO T4	NRO	Classified	$350-450M
6/25/2002		Titan 2	VAFB		NOAA M	NOAA	Meteorological	$30-40M
6/27/2002		Shuttle Columbia	KSC		STS 107	NASA	Crewed	$300M
					SpaceHab Research Double Module	NASA	ISS	
6/XX/02		Long March 4B	Taiyuan		Haiyang 1	State Oceanic Administration (SOA)	Remote Sensing	$25-35M
					Fengyun 1D	China Meteorological Administration	Meterological	
6/XX/02	√	Rockot	Plesetsk	*	Iridium MS-TBA	Iridium LLC	Communications	$12-15M
6/XX/02	√	Ariane 5 ESC-A	Kourou	*	Hot Bird 7	Eutelsat	Communications	$150-180M
6/XX/02		Delta 2 7925-10	CCAFS		Navstar GPS 2R-9	DoD	Navigation	$45-55M
					ProSEDS 2	NASA	Development	
2Q/2002	√	Ariane 5G	Kourou	*	WildBlue 1	WildBlue	Communications	$150-180M
2Q/2002	√	Ariane 44L	Kourou	*	Intelsat 905	Intelsat	Communications	$100-125M
2Q/2002	√	Ariane 5G	Kourou	*	Astra 3A	SES Astra	Communications	$150-180M
2Q/2002	√	Proton	Baikonur	*	Astra 1K	SES Astra	Communications	$75-95M

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+ Denotes FAA-licensed launch.

* Denotes a commercial payload, defined as a spacecraft that serves a commercial function or is operated by a commercial entity.