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Paper Session III-C - Pegasus - History of the First Successful Air-Launched Space Vehicle

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Pegasus®
History of the First Successful Air-Launched Space Vehicle

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Technical Session: Preparing for the Future by Looking at our Past

Abstract

Just a few minutes after noon on April 5th, 1990, a rocket took off into the sky and changed how America perceived small space launch vehicles. The initial flight of Pegasus, dropped from a B-52B aircraft flown from Edwards Air Force Base was a success. Since that time Pegasus has conducted 31 missions, launching more than 70 satellites for government and commercial customers and has flown from 7 different "launch" sites using 5 different Ranges.

This paper will document the history of Pegasus. It will be a historic look into the need that prompted Orbital Sciences Corporation to investigate small space launch vehicles and will cover the concept behind Pegasus and the major technical trades and market forces that changed its course of design. The paper will show how customer inputs into the operational requirements for small satellite launching resulted in capabilities inherent in the current Pegasus XL launch vehicle and Orbital's L-1011 Orbital Carrier Aircraft. It will also briefly cover how Pegasus has been modified to support other classes of missions by using it as the basis for several derivative launch vehicles – the Taurus launch vehicle, the Orbital/Suborbital Program Space Launch Vehicle, also known as the Minotaur, the X-43 booster, and the ground-based mid-course defense system.

Pegasus Pre-History

Pegasus has a very different history than other currently operational launch vehicles as it did not start as a government-funded program, or as a spin-off of a weapons system. It started because Orbital Sciences Corporation could not find a small launch vehicle in the late 1980's to fulfill a business plan.

In the mid 1980's, the concept of a data-only Low Earth Orbit (LEO) constellation of satellites was pursued by Orbital Sciences Corporation. The satellites needed an inexpensive launch vehicle to make the business plan successful. Such a launch vehicle did not exist. The Scout was too expensive, and was a government, not a commercial, product. The Air Force was not interested in commercializing their F-15 based ASAT program. Russia was still part of the Soviet Union, and their boosters were not available. Orbital would have to develop thei own rocket.

High level design trade-offs were made. Invest in ground launch infrastructure or use an aircraft as a launch platform. Should the carrier aircraft be a small and fast aircraft or a low and slow aircraft? Should the rocket have a wing or not? Should control be by vectorable nozzles or control surfaces? LEO payload requirements grew from less than 33 lbs (15 kg) to 200 lbs (90 kg). Specifications were created for hardware and in September, 1987 rocket motor vendors contacted. One of the potential motor vendors guessed from the expansion ratio of the first stage, indicating a high altitude ignition, that Orbital was developing a rocket to go on top of a Peacekeeper or Minuteman booster. This guess became prophetic as the Pegasus-derivative Taurus and OSP Minotaur vehicles using Peacekeeper and Minuteman first stages were developed later; however, that was not Orbital's intention at the time.

In November, 1987 Hercules agreed to become a joint venture partner with Orbital in Pegasus development. Orbital obtained the motor expertise it needed to make Pegasus feasible and Hercules was the sole provider of a new product line.

In late 1987 the Pegasus program held its Preliminary Design Review. The size of the total package was 59 pages long (exclusive of motors) – incredibly short for something as complex as a three stage solid winged space booster using a reusable launch platform. The payload requirement for the launch vehicle was now 500 lbs (226 kg) but grew to 600 lbs (272 kg) – more than 20% - after the meeting.

In 1988 Pegasus won a Defense Advanced Research Projects Agency (DARPA) award for one launch service with options for five more. NASA would provide the B-52 carrier aircraft and site for an Orbital-constructed Vehicle Assembly Building on Edwards Air Force Base. However, the design, development, and funding of the rocket was on Orbital's budget.

In February 1988, the detailed work of turning the concept of Pegasus into a working piece of hardware began. Vendors for the subsystems were contacted. The detailed design trade-offs involved in putting the rocket together were started and engineering began on all the interfaces, specifications, budgets, and details *ad infinitum*, that make up a launch vehicle.

The stage 3 motor had a static firing in March 1989, and the final design review was held in April. The Stage 2 motor was static fired in May and, in July, the Stage 1 motor static firing was completed. In August, a complete inert Pegasus was rolled out and in November, this inert rocket was mated to the B-52 and carried to the drop point to test environments and telemetry. Two more successful captive carry flights were carried out and, on 5 April 1990, Pegasus was dropped off the coast of California, successfully placing the PegSat satellite into orbit. Orbital Sciences Corporation was awarded the United States of America's 1991 National Medal of Technology for the Pegasus program.

Flying Pegasus

Pegasus has now flown 31 times. Over those 31 flights, the program has run into many circumstances that any rocket may encounter, and many that are unique to its air launch heritage. The following is a brief listing of some of the more unique flights – no attempt is made to summarize each flight, to list all of the unique events that were encountered, nor to outline all the payloads we have launched. In the interest of brevity, I will also not be spelling out the satellite acronyms, some of which are quite lengthy.

First Flight – PegSat - 1990

Among its other functions, PegSat was an environmental monitoring satellite that measured the environments of this new rocket. With any new space launch vehicle, there are many analytical predictions that must be verified – payload environments, rocket performance in flight, control response, etc. The initial flight was not flawless, but it did achieve an acceptable orbit, and with the assistance of its telemetry, as well as the environmental information PegSat provided, NASA and Orbital were able to measure payload environments accurately and more accurately model the rocket for future missions.

The first launch of Pegasus also performed a function that would become common for this small rocket – multiple satellites were launched in a load-bearing fashion. The NAVY SECS satellite was carried in addition to PegSat.

Liquid Upper Stage – 1991

For the second launch of Pegasus a liquid fuel fourth stage was added. This stage was inside the cylindrical avionics section and used no payload volume. It was initially called the Precision Injection Kit (PIK) as it was designed to reduce the orbit injection dispersions that the solid fuel third stage rocket had, which limited final orbit accuracy. The acronym for this stage was later changed to Hydrazine Auxiliary Propulsion System (HAPS) as many other uses for a liquid final stage became evident.

Several serious anomalies were encountered on this flight – the stage 1/ stage 2 separation did not occur nominally, and stage 2 ignition occurred with the rocket pitching and yawing in an undesired direction. In addition, the fairing did not separate cleanly and, due to the partially attached fairing, control authority was reversed during a portion of flight. Despite these anomalies the payload of seven small satellites achieved a functional but low orbit, and were able to demonstrate the concept of small tactical communications satellites.

Logistical and Operational Challenges – 1993

The third launch of Pegasus demonstrated its transportability and simple design. Fifty seven days after the first hardware arrived at the Vehicle Assembly Building, Pegasus took off on a cross-country journey to a Florida launch site with the Brazilian satellite SCD-1 on board. A problem with one of the fins during captive carry mandated a return to Edwards Air Force Base prior to launch. The rocket was modified and the satellite was successfully launched several months later.

This launch was also a challenge to command and control. The launch itself departed from the Shuttle landing strip on NASA's Kennedy Space Center (KSC) in Florida. Range safety was performed by the U.S. Air Force's Eastern Test Range, and the launch control center with all the management and senior personnel was on Wallops Flight Facility (WFF) in Virginia, over 600 miles (1000 km) from KSC.

This significant separation of launch center and hardware set a pattern that has also been used successfully in Spain and in Kwajalein.

In addition to the logistical challenges, the SCD-1 satellite was a spin stabilized satellite. Prior to separation of SCD-1, the Pegasus upper stage was spun to 120 RPM to stabilize the satellite.

Rapid Response Photography – 1993

The fourth flight of Pegasus demonstrated one feature designed into Pegasus. The ALEXIS satellite on Pegasus' fourth flight had a cryostat on board that required the satellite be in a vacuum shortly after cryogen loading and payload mate. Less than five days after the payload was mated to the rocket, it was successfully in orbit. While this timeline has shown up in various other launch vehicle user's guides as a theoretical possibility, it has actually been demonstrated on Pegasus.

Another flight instrument was flown in addition to ALEXIS and the OXP-2 secondary – threecameras. Spectacular on-board flight footage was gained from this experiment, showing the rocket dropping away from the aircraft and flying to space, with the thermal protection system dramatically charring as designed. The cameras also recorded the satellite after fairing separation – a record that was to prove helpful in the early orbit operation of the satellite.

Guidance and Extended Operations – 1994

The fifth flight of Pegasus again included the HAPS stage. Due to a slight algorithmic error during the long HAPS motor burn the inertial navigation system incorrectly calculated its position, so the rocket put itself into an orbit that was much lower than intended, burning much less of the hydrazine fuel than intended.

HAPS had been designed to retire on orbit gracefully. Two separate mechanisms were designed in that were predicted to cause the hydrazine to vent safely into space upon overpressure and rupture. Due to the guidance anomaly the HAPS ended up with much more fuel on board than expected. After the satellite had separated and after two years on orbit, Orbital was notified that HAPS had become hundreds of trackable pieces. When filament wound tanks fail, they fail spectacularly and carbon fiber seems particularly trackable. The actual cause of the failure has never been positively determined but steps have been taken to make sure it will never happen again – Pegasus will be completely inert of fuel and pressurant when the batteries expire.

Stretching a Rocket, Changing the Aircraft – 1994

In the early 1990's Orbital made the decision to stretch the rocket to improve capability and to gain performance. To create the Pegasus XL, the first stage of Pegasus was stretched 55 inches (140 cm), and over 6300 lbs (2800 kg) of solid propellant added. The second stage was stretched 18 inches (45 cm) and nearly 2000 lbs (900 kg) of fuel added. The third stage motor had its throat diameter decreased, to expand the effective expansion ratio, enhance burn pressure, and improve specific thrust. These changes boosted performance from 600 lbs (272 kg) to 775 lbs (351 kg) into LEO, for only a small increase in cost.

The original Pegasus rocket had the coefficients for its control algorithms determined analytically. Wind tunnel testing was not performed – Computational Fluid Dynamics (CFD) were used, as well as robust control algorithms. Stretching Pegasus changed the coefficients; the rocket became longer, with different thrust and control coupling profiles. On the sixth flight, the first Pegasus XL failed. The changes proved to be beyond the capability of the CFD analytical techniques for accurate modeling. After the flight wind tunnel testing was used to determine the faults in the analytically derived control laws, showing that CFD does have its limits.

Flight six was also the first mission using the L-1011 as the Pegasus carrier aircraft rather than the B-52. The modified L-1011 had many capabilities that the B-52 was lacking. Orbital modified it with a weight carrying capability well in excess of the B-52 to allow for the Pegasus XL and future Pegasus version's increased mass. The L-1011 also had fully functional flaps, allowing shorter takeoffs and landings – the aircraft would no longer be restricted to long military runways. In addition, air conditioning was now possible for the payload. Pegasus was modified by canting the fins down 23 degrees, allowing the gear doors to close. By carrying the rocket in the center of the aircraft rather then under a wing, ballasting fuel was not needed in the wing – the L-1011 has trans-continental range, something that was missing on the B-52. The aircraft performed well on its maiden voyage.

Flight six also was the inaugural mission for the Vandenberg Air Force Base (VAFB) Vehicle Assembly Building (VAB) – Building 1555. The new facility on VAFB was much larger than the previous facility on Dryden Flight Research Facility on Edwards Air Force Base and allowed Pegasus to have four vehicles under construction simultaneously and two rockets undergoing final integrated testing with the payload.

Integrated Satellite – 1994

Less than 40 days after the unfortunate failure of the first Pegasus XL, the Air Force launched a unique satellite aboard a standard Pegasus off the B-52. This was the last mission from the B-52, the last mission flown from Edwards Air Force Base and the last Pegasus processed at Dryden Flight Research Facility.

The APEX satellite incorporated launch vehicle avionics on the satellite. This posed both opportunities for the satellite in increasing the payload volume under the fairing and mass available to orbit, as well as challenges in having to process the launch vehicle avionics to satellite standards and pre-integration testing of the launch vehicle. APEX was fully successful.

Hybrid Rocket – 1994

The eighth launch of Pegasus carried the first two satellites of the ORBCOMM constellation as well as a satellite for NASA in a load-bearing payload stack. This mission was flown with a standard Pegasus, but in a configuration that became known as hybrid. The fins were canted in order to allow carriage by the L-1011, and the avionics section and wing was that of the new XL configuration. Only the rocket motors had heritage to the standard configuration. All three satellites were successfully put into orbit, and the constellation that had initiated the development of the Pegasus launch vehicle in the first place began to grow.

Separation Failure – 1995

The next mission was another Pegasus XL, the second launch of this configuration. This mission was not successful, due to an interstage separation anomaly. After the failure the Pegasus program brought in Aerospace, the US Air Force, NASA, and its commercial customers to perform a complete review of the rocket that significantly changed the way in which Orbital approached manufacturing and operations. This change was later to be very beneficial in achieving the string of successes that it now enjoys, as well as gaining the ISO-9001 certification that is now mandated by NASA for all launch vehicle contractors. While a later launch failed to successfully deploy the SAC-B and HETE satellites, this was the last launch in which Pegasus did not put its payload into its required orbit.

Dual Payloads – 1996

After four successful launches for the Air Force, BMDO, and NASA, Pegasus was again faced with a new requirement. For its fourteenth mission Pegasus needed to put two NASA non-loadbearing satellites into orbit. For the SAC-B/HETE mission, the program developed a variable-length Dual Payload Attach Fitting (DPAF) to support the satellites separately. The rocket launch was successful but, in the final stages of the mission, one of the launch vehicle batteries suffered a failure, and the satellites could not be separated. The batteries had passed all qualification testing and had significant flight heritage on other launch vehicles. Batteries cannot be fully functionally tested before flight. This was the last time that Pegasus did not successfully separate its satellite(s) once it (they) had been placed in orbit.

This mission was also the first mission flown from Wallops Flight Facility (WFF). WFF had been the control center for the SCD-1 mission, but it's runway and range had not been used for launch since the Scout launches many years previously. Its geographic location and light manifest make it a good location for mid-inclination missions.

International Operations – 1997

For its fifteenth mission Pegasus had a customer requirement to be launched from Spanish soil and for the launch to be controlled from a location yet to be built thousands of miles away. The Pegasus rocket was taken to Torrejon Air Base outside Madrid, Spain for payload mate, and then ferried to the Canary Islands for a retrograde launch. This type of mission has become known as a campaign mission. In a campaign mission the rocket is build at the VAB on VAFB and ferried to the launch site, where it is de-mated from the aircraft and put into a processing bay. The satellite is mated, and the rocket is re-mated to the L-1011 and launched. In this case, there was another ferry flight involved in getting the rocket and satellite from Madrid to the Canary Islands off the coast of Africa.

In addition to building a launch control center in Torrejon to control the launch, Orbital worked with WFF to import and install the NASA mobile range to augment the Spanish assets on Gran Canaria. The WFF mobile range provided complete telemetry and safety support and added a dimension of mobility to Pegasus operations.

This mission also carried the first Celestis payload – human cremains. Pegasus put Gene Roddenberry, Timothy Leary, and Gerard K. O'Neil among others into their final orbits in space.

String of Operations – 1997 – 1998

During the period from the launch of the Spanish MINSAT-01 until the WIRE satellite Pegasus launched thirty three satellites in two years using a single launch and integration crew and carrier aircraft. All these launches were successful and included such notable firsts as two launches from the same launch platform (the L-1011) in less than 30 days, another integrated satellite, SeaStar, that still holds the record as the heaviest and largest satellite Pegasus has launched, the first campaign launch from Wallops Flight Facility, 24 ORBCOMM satellites launched on three rockets, and the first mission for the NASA Ultralight contract, where the customer could purchase half a ride on Pegasus.

External Experiments - 1998

For its twenty fourth launch the primary payload was the Brazilian SCD-2 satellite, a twin satellite to SCD-1. As a secondary payload, NASA put a metallic glove on the wing of the rocket, measuring transonic and hypersonic shock wave transitions. The launch was successful and the program learned quite a bit about the post-separation behavior of the winged first stage as the NASA telemetry system stayed operational almost until spashdown of the stage 1/wing assembly.

Solid Hydrogen – 1999

For its twenty sixth launch the WIRE satellite carried had a small cryostat filled with solid hydrogen. Solid hydrogen transforms directly from solid to gas extremely quickly if vacuum is lost and, due to the flammable nature of hydrogen, very special precautions were taken. An exhaust stack to safely vent the hydrogen in case of vacuum leakage had to be developed, and the gas vented (if necessary) through the Pegasus fairing and around the L-1011 to burn harmlessly in the air. In addition, inert purge gas had to be carried for this vent stack, so that the hydrogen would not freeze the air in the vent stack and form a plug. This is one of the most recognizable Pegasus launches – the L-1011 wore a "belt" during the mission to maintain integrity of the aircraft hull. The launch was successful, and the satellite placed into orbit with its full load of hydrogen intact.

Dual Orbits – 1999

The two payloads on board Pegasus' twenty seventh launch required different and unique orbits. In addition, the forward payload was a "Thompson spinner" (spinning end over end, rather than axially). To perform the mission, the rocket was required to reach 4 different orbits. HAPS and the Pegasus control system performed flawlessly, reaching the first orbit accurately, putting the forward satellite into its Thompson spin, stabilizing the rocket after forward satellite separation, separating the adapter cone (the aft payload was a load-bearing design), performing a Hohlmann transfer of the aft satellite to its required orbit and separating it over the designated ground station, and then deorbiting itself before venting all the propellants and gases to render the final stage inert.

Equatorial Operations – 2000

Pegasus thirtieth launch was another first, demonstrating another capability of air launch. Using a two day ferry operation, Pegasus flew out to the Kwajalein Atoll, a United States-leased island in the Territory of the Marshall Islands. By launching from Kwajalein and using range assets that are normally used to support suborbital missile tests, Pegasus was able to reach an orbital inclination of just 2 degrees. By launching into an orbital inclination this low, the satellite avoids significant overflight of the South Atlantic Anomaly (SAA), and can use a sensor optimized for deep space observations without having to shield or filter the radiations of the SAA.

This mission, originally a dual satellite mission, was the last of the hybrid Pegasus missions to launch and marked a perfect string of payload insertions into orbit – 10 for 10.

Delays and First Recycle Launch – 2002

After the October launch, the Pegasus program started preparing for the next launch, a ferry mission out of Florida. Little did the program realize that a long and complex series of delays would mean a 15 month hiatus from exercising the launch team.

The first delay occurred when the satellite encountered extreme environments during a vibration test due to a malfunctioning piece of equipment and was severely damaged.

The second delay occurred when a customer review team had the satellite's electronic boxes opened for inspection.

The third delay was to allow Pegasus to modify hardware to prevent recurrence of an anomaly that happened on the last launch – the launch from Kwajalein.

The fourth delay occurred just days before launch. The mission had already flown to Florida and was in final preparations prior to launch when the X-43 launch vehicle failed. The X-43 is a suborbital test craft that uses a highly modified standard Pegasus first stage as a booster to push a wedge-shaped, hydrogen powered research craft to hypersonic velocity. While the X-43 flies in a substantially different flight regime than Pegasus and is extremely different in outer mold line, there was sufficient commonality between the vehicles that the Pegasus mission was put on hold by the customer and eventually returned to California until Pegasus could be cleared for flight.

The fifth delay was caused indirectly by failure of the Taurus booster. Taurus uses Pegasus stages, although in somewhat different configurations for its second, third, and fourth stages. The Taurus failure appears to have been caused by a component that is not used on Pegasus, however in reviewing the documentation, some qualification shortfalls were found, and Pegasus hardware was replaced.

The sixth and final delay happened due to failure of a suborbital booster Boeing launched for a national missile defense test. While the rocket had little commonality with Pegasus, both had solid rocket motors built by Alliant Techsystems, and both used similar construction techniques and materials.

With all the delays behind it, Pegasus finally headed to Florida for launch. On launch day, just prior to terminal count, a period of very high activity, communications with the aircraft became intermittent. The launch team decided to abort the launch attempt and recycle. To recycle a Pegasus mission means flying the aircraft through the launch point without dropping, and then circling around and trying again. This had been designed into the Pegasus launch procedures and is an option whenever the spacecraft launch window allows, but had never been required on previous launch attempts. Communications were firmly restored during the flight, and Pegasus launched for its seventeenth consecutive successful mission.

Derivative Vehicles

Six derivative vehicles have been developed or are in development based in part on the original Pegasus Launch Vehicle. Taurus, Pegasus XL, Minotaur, X-43, Taurus XL and the Dual Boost Vehicle have all come from the initial Pegasus rocket systems design. The standard Pegasus in its original and hybrid configurations has launched ten times.

The first of the derivative vehicles was Taurus. Taurus was designed as a quick reaction launch vehicle that could be launched under austere conditions using a Peacekeeper first stage or Castor 120 solid rocket motor as its first stage. The upper three stages are the Pegasus Orion motors, modified for ground launch and to carry the larger payloads that Taurus is capable of putting into orbit. Its first launch was in 1994, three years after the first launch of Pegasus. Taurus has been launched six times. Taurus has a payload capacity about 4 times larger than standard Pegasus.

Pegasus XL has been discussed previously, and was first launched successfully five years after the initial Pegasus launch. Pegasus XL has been launched 21 times. Stretching Pegasus into the XL increased performance by more than 25%.

Minotaur is the name for the space launch version of the Orbital Suborbital Program vehicles. This program is designed to use Minuteman stages to meet a variety of U.S. Government needs, one of which is inexpensive space access. The Minotaur uses the first and second stages of a Minuteman ICBM and the second and third stages, and fairing from Pegasus. The Minotaur was first launched in 2000, slightly over 9 years after the first Pegasus launch and has been launched twice. Minotaur has around 40% more performance than a Pegasus XL.

The X-43 uses a modified Pegasus first stage to boost a scramjet to ignition velocities. The first X-43 launch was eleven years after the first Pegasus flight. The X-43 has launched once and has two more launches planned.

The Taurus XL is a stretched version of Taurus. Like Pegasus XL, the Taurus XL uses stretched versions of the Orion 50 motor for its second and third stages. First flight is currently scheduled for 2003.

Orbital has bid a wingless ground-launched version of Pegasus to serve as the interceptor booster for the ground-based mid-course defense system.

Mission	Date	Payload	Orbit/Lnch/Rng	Result
XF1 Standard Pegasus	5 Apr 90	NASA PegSat DoD SECS	273x370nm 94.1º EAFB/WR	Complete Success
XF2 Standard Pegasus w/ HAPS	19 Jul 91	DoD 7x MicroSats	192x245nm 82.0º EAFB/WR	Low Orbit
F3 Standard Pegasus	2 Feb 93	Comm SCD-1	393x427nm 25.0º KSC/ER	Complete Success
F4 Standard Pegasus	25 Apr 93	DoD/DoE ALEXIS Comm OXP-2	404x450nm 69.9º EAFB/WR	Complete Success
F5 Standard Pegasus w/ HAPS	19 May 94	DoD STEP-M2	325x443nm 81.9º EAFB/WR	Low Orbit
F6 Pegasus XL	27 Jun 94	DoD STEP-M1	Suborbital VAFB/WR	Mission Failure
F7 Integrated Standard Pegasus	3 Aug 94	DoD APEX	195x1372nm 70.0º EAFB/WR	Complete Success
F8 Hybrid Pegasus	3 Apr 95	Comm 2x ORBCOMM NASA Orbview-1	395x411nm 70.0º VAFB/WR	Complete Success

Mission	**Date**	**Payload**	**Orbit/Lnch/Rng**	**Result**
F9 Pegasus XL	22 Jun 95	DoD STEP-M3	Suborbital VAFB/WR	Mission Failure
F10 Pegasus XL	8 Mar 96	DoD REX-2	451x434nm 90.0º VAFB/WR	Complete Success
F11 Hybrid Pegasus	16 May 96	DoD MSTI-3	293 x 363km 97.1º VAFB/WR	Complete Success
F12 Pegasus XL	2 Jul 96	NASA TOMS	341x943km 97.4º VAFB/WR	Complete Success
F13 Pegasus XL	21 Aug 96	NASA FAST	350x4170km 83.0º VAFB/WR	Complete Success
F14 Pegasus XL w/ DPAF	4 Nov 96	NASA SAC-B NASA HETE	488x555km 38.0º WFF/WFF	Mission Failure
F15 Pegasus XL	21 Apr 97	Comm MINISAT-01	563x582km 151.0º Canary Isl/WFFM	Complete Success
F16 Integrated Pegasus XL	1 Aug 97	Comm OrbView-2	300x302km 98.3º VAFB/WR	Complete Success
F17 Pegasus XL	29 Aug 97	DoD FORTE	800x833km 70.0º VAFB/WR	Complete Success
F18 Pegasus XL	22 Oct 97	DoD STEP-M4	430x511km 45.0º WFF/WFF	Complete Success
F19 Pegasus XL w/ HAPS	23 Dec 97	Comm 8x ORBCOMM	822x824km 45.0º WFF/WFF	Complete Success
F20 Pegasus XL	25 Feb 98	NASA SNOE Comm BATSAT	582x542km 97.8º VAFB/WR	Complete Success
F21Pegasus XL	1 Apr 98	NASA TRACE	600x649km 97.8º VAFB/WR	Complete Success
F22 Pegasus XL w/ HAPS	2 Aug 98	Comm 8x ORBCOMM	819x826km 45.0º WFF/WFF	Complete Success
F23 Pegasus XL w/ HAPS	23 Sep 98	Comm 8x ORBCOMM	811x826km 45.0º WFF/WFF	Complete Success
F24 Hybrid Pegasus	22 Oct 98	Comm SCD-2 NASA Wing Glove	750x767km 24.9º CCAFS/WR	Complete Success
F25 Pegasus XL	5 Dec 98	NASA SWAS	638x663km 69.9º VAFB/WR	Complete Success
F26 Pegasus XL	4 Mar 99	NASA WIRE	539x598km 97.5º VAFB/WR	Complete Success
F27 Pegasus XL w/ HAPS	17 May 99	NASA TERRIERS DoD MUBLCOM	551x557km 97.7º 774x788km 97.7º VAFB/WR	Complete Success
F28 Pegasus XL w/ HAPS	4 Dec 99	Comm 7x ORBCOMM	826x829km 45.0º WFF/WFF	Complete Success
F29 Pegasus XL	7 Jun 00	Comm TSX-5	410x1712km 68.9º WFF/WFF	Complete Success
F30 Hybrid Pegasus	9 Oct 00	NASA HETE-2	592x652km 1.9º KMR/KMR	Complete Success
F31 Pegasus XL	5 Feb 02	NASA HESSI	586x602km 38.0º CCAFS/ER	Complete Success