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Space Exploration Via Technology Demonstration and Small Satellite Missions Flown on Reusable Launch Vehicles

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Abstract

In January 2004, President Bush announced his new vision for Space Exploration, calling for a step-by-step approach to opening new frontiers, furthering scientific research, returning to the Moon, and ultimately enabling exploration to Mars and other destinations. Considering the ultimate objective in exploring the universe and beyond, what are the tools needed to further this vision? A few key components come to mind: affordable and frequent access to space, technology demonstration platforms, and low cost small satellite and robotic missions. Reusable launch vehicles (RLVs), such as Kistler Aerospace's K-1, and demonstration missions for technology experiments and small satellites together can play a key role in implementing the U.S. vision for space exploration.

Conducting exploration missions will require cost-effective launch alternatives to existing services and increased flight opportunities for experiments and small satellites. The K-1 will be a potential launch service provider to expand access to space for exploration, such as for new small satellite missions (like Clementine from 1994) or the more recent Mars lunar and rover missions. For example, the K-1 Multiple Small Payload Adapter-1 can fly up to 3 mini-satellites, with satellite mass up to 1,100 lb (500 kg) each, and the K-1 Multiple Small Payload Adapter-2 can fly up to 8 micro-satellites, with satellite mass up to 275 lb (125 kg) each, along with a primary payload. Users share the price of a K-1 LEO launch and integration. For small exploration missions to Lunar and Mars injection orbits, the K-1 can be outfitted with an Active Dispenser (expendable upper stage) to fly dedicated or multiple small satellite rideshare missions for exploration purposes.

In addition, space exploration will require testing and re-testing of critical technologies needed for going to the Moon, Mars and beyond. The K-1 provides a flight-test platform for demonstrating technologies, such as advanced structures, materials, thermal protection systems, avionics, microgravity, and others, in a full-flight environment on a typical K-1 mission to LEO. Kistler has already defined standard experiment environments, accommodations and interfaces services to facilitate integration.

The U.S. exploration vision has the potential to drive innovation. This paper outlines the potential leadership role that small satellite and technology demonstration missions flown on reusable launch vehicles such as the K-1 can play in implementing this vision.

Vision for Space Exploration

The Vision for U.S. Space Exploration[1] calls for a "Renewed Spirit of Discovery" to explore the universe and to advance U.S. scientific, security, and economic interests through a robust space exploration program. The goals and objectives of this program are to:

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
- Extend human presence across the solar system;
- Develop innovative technologies, knowledge, and infrastructures; and
- Promote international and commercial participation in exploration.

Technology demonstration, small satellites, and robotic missions will play a key role in implementing the vision, and can be enabled through the use of reusable launch vehicles such as the K-1. Kistler Aerospace is developing the first, fully reusable, commercially funded launch system. As such, the Kistler K-1 will not only minimize the cost of exploration, but also address the President's stated goal of fostering commercial space systems development and use.

Small Satellite and Robotic Missions

Small satellite and robotic missions have already contributed to space exploration missions. Numerous small satellites have demonstrated technologies such as lunar swingby techniques, miniature seekers, and spaceflight techniques. Exploration missions have made scientific observations of the Moon, Mars, asteroids, and cometary targets. Figure 1 lists some of these missions.

For the new space exploration vision, similar missions can be conducted to increase scientific, national security and economic value. Examples of small exploration missions include:

- Space weather station
- Solar observatory
- Earth observatory
- Lunar and Mars resource mapping
- Lunar and Mars positioning satellites
- In-space communications relays
- Logistics support.

Small payloads have an advantage of lower cost and lower risk and can be flown on multiple missions to spread the risk and enable testing and re-testing of critical components – this contributes to making the space exploration vision sustainable and affordable. Small missions will require the use of affordable launch systems as well. Commercially-provided services can reduce transportation costs and expand access to space for a wide range of users. Early and low-cost access to the lunar surface, for example, can permit early technology development activities and activation for extraction systems on the Moon.

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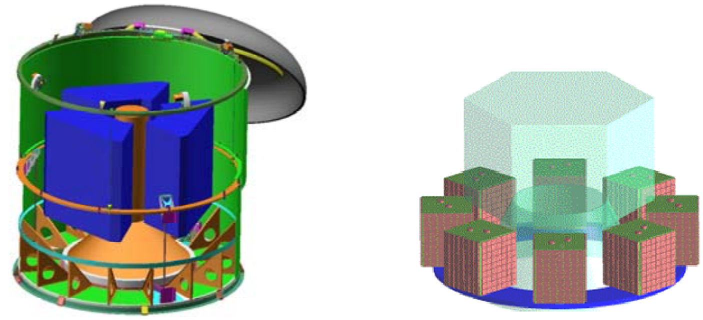
[1] "Renewed Spirit of Discovery," The President's Vision for U.S. Space Exploration, President George W. Bush, January 14, 2004.

Mission Name	Launch Date	Nation	Mission Purpose
Giotto	1985	ESA	Study Comet P/Halley
Pegsat	1990	US	Chemical release experiment
Ulysses	1990	US/ESA	Fly over the poles of the sun
Hiten/Muses-A	1990	Japan	Lunar swingby techniques, ejected lunar orbiter
Solar	1991	Japan	X-ray imaging of sun
MSTI	1992	US	Test Miniature Seeker Technology
Clementine	1994	US	Sensor technology demo; map lunar surface
MSTI-2	1994	US	Investigate paceflight techniques and technology
Mars Pathfinder	1996	US	Mars lander with surface rover
MSTI-3	1996	US	Sensor technology tests
NEAR	1996	US	Rendezvous with and orbit asteroid Eros
ACE	1997	US	Determine composition of interplanetary matter
Deep Space 1	1998	US	To flyby asteroid and cometary targets
Lunar Prospector	1998	US	Determine origin, evolution, and state of lunar resources
Mars Climate Orbiter	1998	US	Mapping and weather studies of Mars
TRACE	1998	US	Ultraviolet imaging telescope for studies of the sun
Noxom/Planet-B	1998	Japan	Test spacecraft technology, study Mars atmosphere
Mars Polar Lander	1999	US	Study Martian volatiles and climate history
Stardust	1999	US	Fly near comet and recover and return cometary material
Simplesat	2001	US	Test methods for building cheap astronomical satellites
TIMED	2001	US	Study the thermosphere, mesosphere and lower ionosphere
Odin	2001	Sweden	Study galactic molecular clouds
CONTOUR	2002	US	Explore three comets
HESSI	2002	US	Imaging hard X-ray flares from the sun
Galex	2003	US	Observe galaxies in ultraviolet wavelengths
MER-A	2003	US	Search, characterize rocks and soils on Mars
MER-B	2003	US	Search, characterize rocks and soils on Mars
SIRTF	2003	US	Observatory for infrared astronomy
Hayabusa/Muses-C	2003	Japan	Technology demo, collect, return sample from asteroid

Reference: www.astronautica.com

Figure 1. Examples of Historical Small Satellite Exploration Mission

The K-1 can perform such missions. For LEO, the K-1 vehicle can accommodate multiple small LEO satellites, as shown in Figure 2. The K-1 Multiple Small Payload Adapter-1 (MPAS), designed by Astrium Ltd based on the Ariane ASAP adapter, can fly up to 3 mini-satellites, with satellite mass up to 1,100 lbs (500 kg) each, and the K-1 MPAS-2 can fly up to 8 micro-satellites, with satellite mass up to 275 lbs (125 kg) each, along with a primary payload. Small satellites can fly together and share the price of a K-1 launch.



K-1 Payload Module Shown with Multiple Satellites to LEO

8 Microsatellites with Primary Payload

Figure 2. Multiple Small Satellites on the K-1

For exploration missions to interplanetary targets, the K-1, equipped with an Active Dispenser, can place approximately 2,000 lb (900 kg) into Low Lunar Orbit (LLO), or can deliver a 1,000 lb (450 kg) payload to the Lunar surface. This capability enables the deployment of scientific, communication, or navigation satellites in LLO or rovers weighing approximately 700 lb (320 kg) on the Moon's surface. These sizes are consistent with the sizes of probes and rovers that have been previously sent to, or are scheduled to be flown to the Moon or nearby planets.

The K-1 Active Dispenser's performance capability encompasses a broad range of space missions and standard spacecraft buses. More detail on the Active Dispenser can be found in the K-1 Payload User's Guide, Addendum A, available for download at the Kistler website (http://www.kistleraerospace.com).

Technology Demonstration Missions

Technology demonstration will also be an important part of implementing the space exploration vision. From developing new sensors to testing autonomous rendezvous to performing fuel transfer in space, the nation will need the ability to test and re-test technologies to reduce risk incrementally. Such experiments could include advanced structures, materials, thermal protection systems, avionics, advanced checkout and control, integrated health management systems, communication systems, rendezvous sensors, autonomous rendezvous and proximity operations, and landing systems.

The K-1 vehicle will provide access to space for non-deployable flight experiments to demonstrate advanced launch vehicle technologies in a true orbital flight regime – and return experiments to Earth for checkout and reflight. Experiments may be flown internally (for active experiments) or externally (for passive experiments) on the K-1, as shown in Figure 3.

To facilitate shorter integration times, the K-1 has a number of mounting locations for experiments on the first and second stages, employing standard interfaces and mounting structures, for both externally mounted and internally mounted experiments. The experiment accommodations are described in *The K-1 Vehicle TA-10 Flight Experiment Design and Requirements Document*, available for download from Kistler's website (www.kistleraerospace.com). Technology experiments can rideshare on any K-1 flight, and the standard interfaces ensure no interference with the primary payload on the flight.

Flight opportunities for experiments in microgravity are in high demand in the fields of Biotechnology, Combustion Science, Fluid Physics, Fundamental Physics, and Materials Science. Researchers in such fields need low-cost, frequent access to and return from space. Repeat experiments are essential to accumulate enough data for peer review of their work. The availability and high cost of launch have been limiting factors. Affordability and routine flights are significant advantages for commercial operations such as the Kistler K-1 system.

The K-1 provides a high-quality microgravity environment on every flight for secondary payloads. Every launch dollar saved is a research dollar gained to the scientific community. In these days of tight research budgets, Kistler's K-1 vehicle is an ideal alternative to existing platforms.

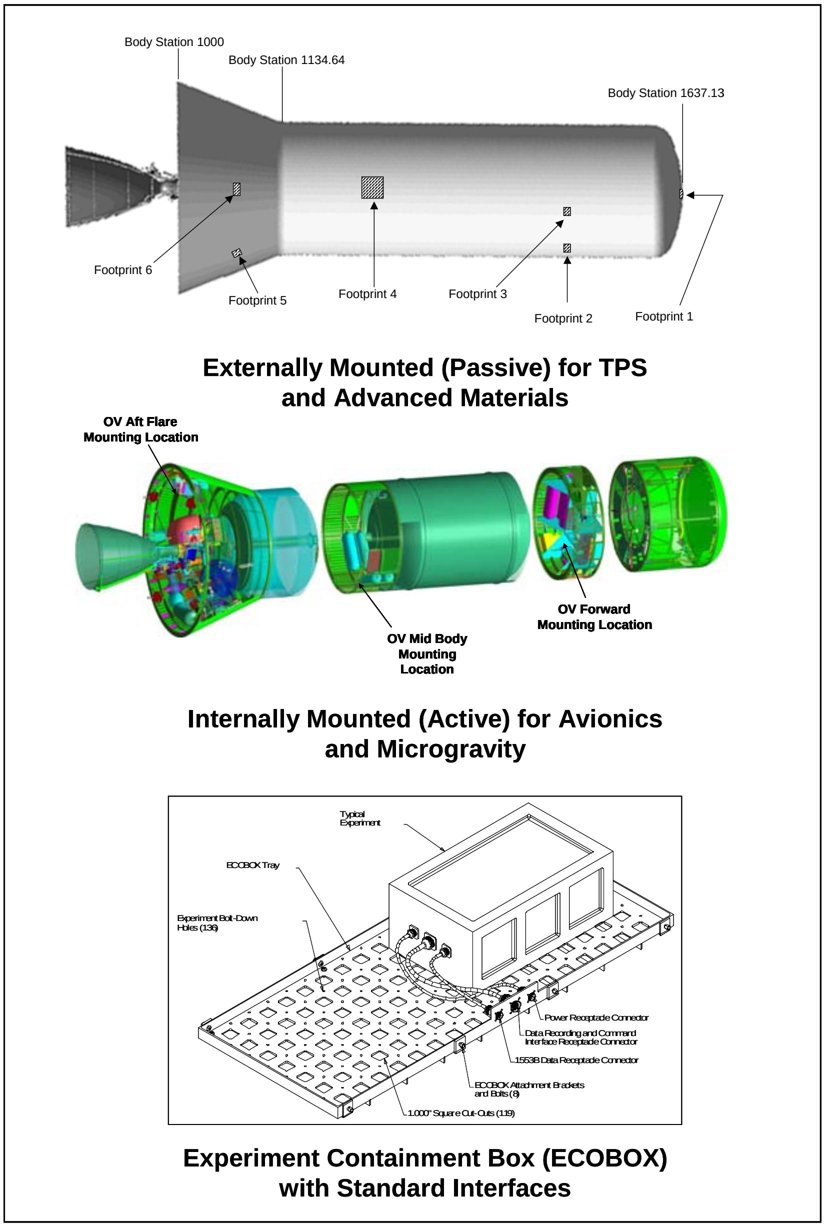


Figure 3. K-1 Technology Experiment Accommodations

The K-1 Reusable Aerospace Vehicle

The K-1 vehicle is a two-stage, fully reusable aerospace vehicle designed to deliver payloads to a variety of orbits. The overall K-1 vehicle has a mass of 841,000 lbm (382,300 kg) at liftoff. The first stage, called the Launch Assist Platform (LAP), uses three gimbaled liquid oxygen (LOX)/ kerosene engines during the boost phase. Two Aerojet AJ26-58 engines and one AJ26-59 engine power the first stage. The second stage, called the Orbital Vehicle (OV), uses a single Aerojet AJ26-60 engine (an altitude version of the AJ26-58 engine). The engines are U.S. modifications of the fully developed, extensively tested core of the NK-33/NK-43 engines originally designed for the Russian Manned Moon Program in the mid 1960s and subsequently placed in storage in Samara, Russia, for over two decades. The engines have been modified to include modern U.S. electronic controllers, ignition systems, control valves, and thrust vector control systems.

The K-1 combines existing and tested propulsion technology with advanced lightweight composite structures to create a low-cost and reliable vehicle capable of delivering a variety of payloads to a wide range of altitudes and inclinations. Each stage carries its own suite of redundant avionics and operates autonomously and includes numerous safety and reliability features including a triplex fault-tolerant avionics architecture, an extensive Integrated Vehicle Health Management (IVHM) system, and an GN&C system capable of performing ascent, on-orbit and entry operations. Both stages return to the launch site using a landing system of parachutes and airbags. The K-1 Vehicle profile is shown in Figure 4.

The K-1 will provide affordable, responsive access to space for many customers – NASA, Department of Defense and commercial. The K-1 can deliver approximately 12,500 lbs (5,700 kg) to LEO (due east) as well as 3,500 lbs (1,570 kg) to GTO and 2,000-3,000 lbs (900-1,400 kg) to interplanetary targets (with an Active Dispenser upper stage). For ISS missions, the K-1 can deliver 7,000 lbs (3,200 kg) of pressurized cargo to the ISS, return more than 2,000 pounds (900 kg) of recoverable down mass to earth, and have the capability to reboost the ISS up to 40 miles (25 km). As a result the K-1 is the most likely new candidate for the U.S. to maintain vital support of the ISS. The K-1 will be able to service the ISS as frequently as needed, with regular monthly flights for routine logistics and launch on demand service.

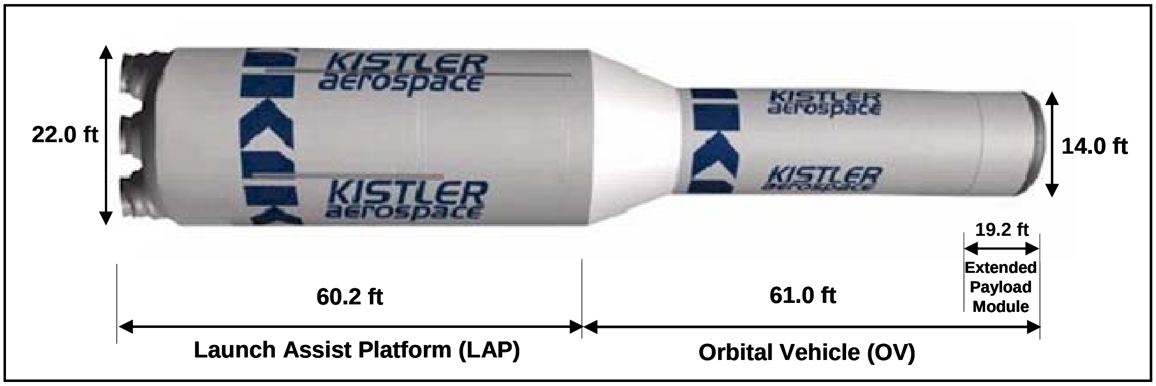


Figure 4. K-1 Vehicle Profile

The K-1 has an assortment of reusable, interchangeable Payload Modules, as shown in Figure 5, to enable a variety of missions, flexible mission planning, and responsive space operations. Payload delivery to LEO uses either the Standard Payload Module or the Extended Payload Module. GTO and space exploration missions use an Active Dispenser (third stage), and ISS resupply missions use an ISS Cargo Module.

Kistler currently plans to establish two launch sites for operating the K-1 reusable aerospace vehicles: Woomera, Australia and Nevada, USA. Environmental approval has been received at both sites. Test flights and initial commercial operations are planned from Spaceport Woomera, located in the Woomera Prohibited Area, a 127,000 square kilometer region in the desert of South Australia, about 280 miles (470 km) north of Adelaide. A second launch site is planned in the U.S., at the Nevada Test Site, near Las Vegas, Nevada, USA, after demonstrating successful flights in Australia. The launch sites will have nearly identical facilities, infrastructure and support equipment. Reynold Smith and Hill (RS&H) of Merritt Island, Florida, which designed launch pads at Cape Canaveral, has completed detailed design of the K-1 launch facility and support equipment. In addition, Kistler has surveyed multiple other sites for suitability of potential K-1 operations in the continental United States.

More detail on the K-1's design, launch environments, interfaces, performance, and launch facilities can be found in the K-1 Payload User's Guide, available for download at the Kistler website (http://www.kistleraerospace.com).

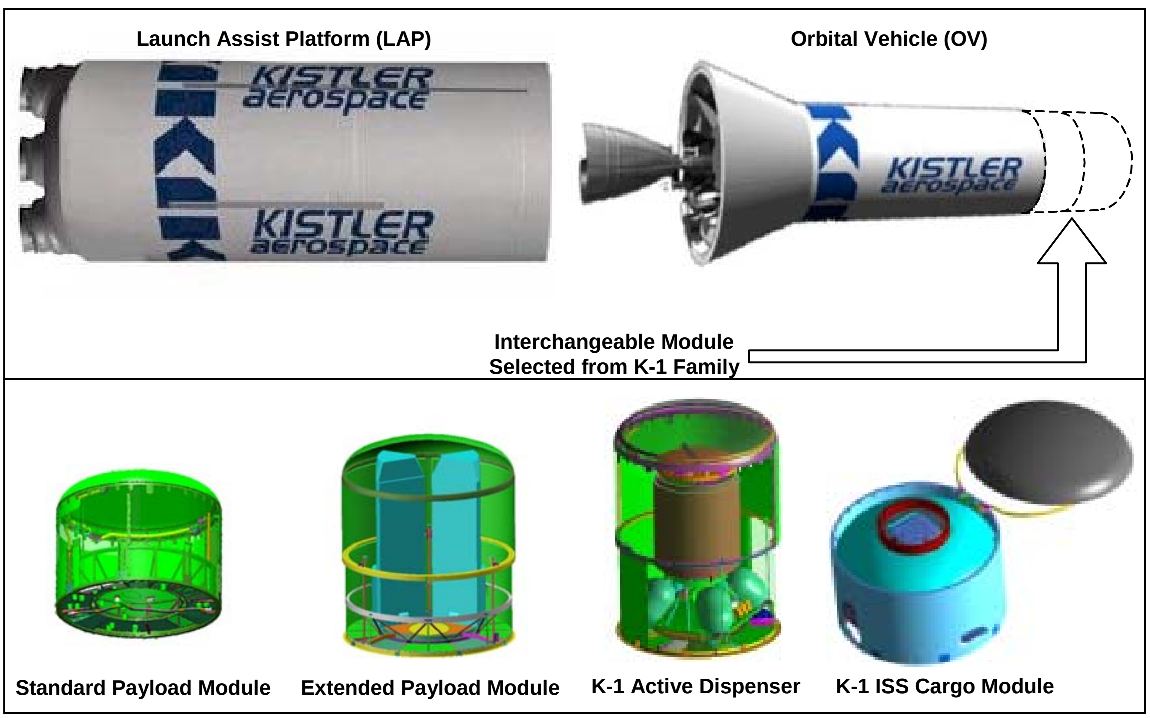


Figure 5. Kistler K-1 has Multiple Mission Capability

Background on Kistler Aerospace Corporation

Kistler Aerospace Corporation is a privately funded, U.S. small business, headquartered in Washington State. Kistler is developing the K-1 fully reusable aerospace vehicle, designed to deliver payloads to orbit and provide a low-cost alternative to single-use launch vehicles. The company intends the K-1 to become the reliable, low-cost provider of launch services for commercial, civil, and military payloads destined for a wide range of orbits. The K-1 mission capability includes cargo resupply to and return from the ISS; satellites, scientific payloads and technology experiments to LEO, MEO, and GTO/GEO; and space exploration missions to the Moon, Mars and Beyond.

Kistler plans to build a fleet of K-1 vehicles with a large annual flight capacity at a list price of $17 million per flight to LEO, significantly lower than the price of existing expendable launch vehicles with similar performance capability. K-1 missions are conducted on a commercial basis and mission-specific hardware and integration are priced separately.

Kistler's senior management team has been involved in the United States space program for decades. Kistler is the owner/operator of the K-1 program, with detailed design, manufacturing and test done by its contractors. The K-1 contractor team includes some of the best the United States has to offer: Northrop Grumman Corporation (composite structures); Lockheed Martin Space Systems – Michoud Operations (aluminum propellant and oxidizer tanks); Aerojet – General Corporation (propulsion systems); Honeywell (avionics); Draper Laboratory (guidance and control); Irvin Aerospace (landing systems); Oceaneering Space Systems (thermal protection); as well as a number of smaller contractors.

The first K-1 vehicle is 75% built, 85% design complete, and first guidance, navigation and control (GN&C) flight software is 100% complete. All system requirements tasks have been completed, and numerous tests conducted, including full-length firing of the K-1's main rocket engines, full-scale drop tests of the parachute recovery system, and Hardware-in-the-Loop testing of the K-1 flight avionics hardware and software. Some of this hardware is shown in Figure 6.

Kistler has raised more than $600 million in private investment and spent more than $800 million on the K-1 Program. Kistler is in the process of finalizing its Plan of Reorganization to enable it to emerge from Chapter 11 with the support of its largest creditor, Bay Harbour Management LLC, a well-known firm specializing in restructuring companies.

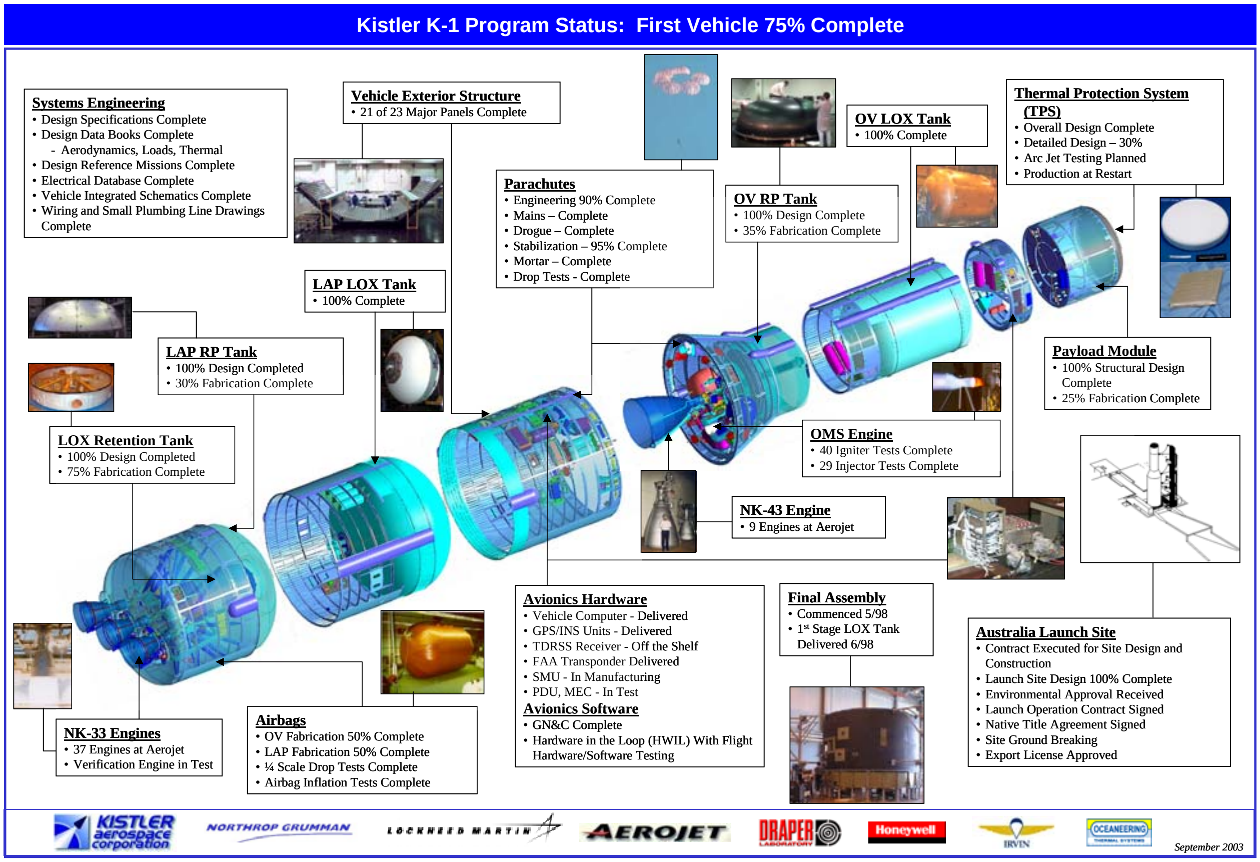


Figure 6. K-1 Hardware is 75% Complete

Summary

Small satellite missions have historically contributed to space exploration and are poised to play a significant role in the new space exploration vision. Conducting exploration missions will require cost-effective launch alternatives to existing services and increased flight opportunities for experiments and small satellites. The K-1 will be a potential launch service provider to expand access to space for small satellite missions, technology demonstration, and exploration missions to the Moon, Mars and Beyond.