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K-1 Small Satellite Missions

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Abstract

Kistler Aerospace Corporation is building the K-1, the world's first fully reusable aerospace vehicle. By reusing each K-1 multiple times, Kistler plans to reduce the cost of access to space while providing a reliable launch on-demand capability to low-earth orbit and beyond.

The K-1 is designed to carry a wide range of payloads to a variety of orbits. Kistler and Astrium Ltd. (formerly Matra Marconi Space UK) have initiated an effort to design reusable dispensers for multiple small payloads for use on the K-1. One of these dispensers may be used to deploy small satellites during the K-1's flight test program.

Kistler is investigating the feasibility of flying dedicated, multiple small payload missions. Such a mission may launch multiple small payloads from a single customer or small payloads from different customers. To facilitate ride-sharing opportunities, Kistler may issue an Announcement of Opportunity for multiple small payloads to fly to a predetermined orbit at a predetermined date. The orbit would be selected to be compatible with the requirements of as many small payload customers as possible. To avoid expensive recurring costs, small payloads would make use of standard interfaces and verification plans determined by Kistler. Kistler may employ the services of a broker to coordinate integration of multiple customers. If there is sufficient demand, Kistler can schedule regular fixed "departures" for small payloads. This would eliminate the need to match small payloads with a compatible primary payload customer, increasing the number of access to space opportunities open to small satellites.

Introduction

The cost of delivery to orbit is often greater than the cost of manufacturing a satellite. This is particularly true for small satellite programs. Measured on a cost per kilogram basis, the cost of a ride on a small launch vehicle is generally more expensive than the cost of launch on a larger vehicle. Opportunities to ride as secondary payloads with a larger satellite are therefore in great demand, but the need for compatibility with the larger satellite's orbital requirements and schedule severely limits the available supply of such opportunities.

Ridesharing opportunities are further restricted by the lack of standard interfaces, envelopes, and verification plans for small satellites. In most cases, to accommodate a small secondary payload, a significant amount of non-recurring engineering and hardware development is required to develop and qualify a dispenser unique to the small satellite.

An analogy can be drawn here to the passenger aviation industry. The procedure with which launch services are purchased today is akin to practices in the charter aviation industry. Charters generally serve a single customer on a per-flight basis, flying where that customer wants to go at a requested time. This may be a cost-effective solution for large groups traveling together, or for large cargos, but for a small group of travelers or for a single traveler, it is prohibitively expensive. To truly extend the analogy between launch services and charter aviation, the charter airline would destroy each airplane after completing the revenue flight, as is the practice of expendable launch vehicle providers. These practices explain why access to space is so costly.

To make aviation affordable to small groups of travelers, airlines operate fixed routes with regularly scheduled departures. Flights are scheduled more frequently on popular routes. These departures are scheduled at specific times well in advance of selling tickets for every seat on the plane, and will fly even if they do not carry a full passenger load. Passengers sit in standard sized seats and limits are placed on the weight and volume of their luggage. Planes operating on these routes are used thousands of times and optimized for quick turnaround. Travelers benefit from frequent, low-cost service. The average person could not possibly afford to travel by air conveniently if all airlines operated by charter only.

To vastly expand flight opportunities for small satellites while reducing launch costs, the launch services industry must move away from the charter aviation paradigm and towards the paradigm of frequently scheduled airline routes. This is not possible through use of expensive, single-use, expendable launch vehicles, which are often built custom for a specific mission, and must fly nearly a full payload to recoup the cost of manufacture. This may soon change, however.

Kistler Aerospace Corporation is developing the K-1, the world's first fully reusable aerospace vehicle. Each K-1 is designed for reuse up to 100 times, with a minimum of refurbishment required between flights. By amortizing the development costs of each vehicle over many flights, Kistler plans to dramatically reduce the cost of access to space. Each vehicle is designed for a nine-day turnaround between launches, enabling frequent, routine flight opportunities.

Kistler has teamed with Astrium Ltd. (formerly Matra Marconi Space UK) to develop reusable small payload dispensers for the K-1. Astrium, the largest space systems company in Europe and the third largest space systems company in the world, manufactures the Ariane Structure for Auxiliary Payloads (ASAP) for the Ariane 4 and Ariane 5. Astrium has designed a Multiple Payload Adapter System (MPAS) for the K-1, designed to deploy small satellites as secondary payloads or for dedicated small satellite missions.

Kistler is studying the feasibility of scheduling fixed departures for dedicated small satellite missions to popular orbits, a concept referred to here as, "Ticket-to-Orbit." Rather than selling an entire launch to one customer, Kistler (or a broker) may sell "seats" on the MPAS, enabling a small satellite program to purchase a ride without the need to canvas for a compatible primary payload. The small satellite would need to fit a standard interface and mass/volume envelope, as well as undergo a verification program to ensure non-interference with other payloads. Kistler would offer this launch with a standard set of services on a low, fixed-price basis. Non-standard services would be offered for additional cost. Kistler can offer these services because the marginal launch cost of the reusable K-1 is far below the marginal cost of an ELV with similar payload capacity.

This paper first describes Kistler Aerospace Corporation and the K-1 vehicle briefly. It then describes Astrium's MPAS designs and discusses how Ticket-to-Orbit may work.

Overview of Kistler Aerospace Corporation

Kistler Aerospace Corporation was formed in 1993 by Walter Kistler, the co-founder of Kistler-Morse Corporation, and Bob Citron, the founder of SPACEHAB, Inc. Since 1995, Kistler has been led by Chairman Robert Wang and Chief Executive Officer Dr. George E. Mueller, the former head of NASA's Apollo Manned Space Program. Kistler Aerospace's mission is to develop and operate the world's first fully reusable aerospace vehicles, called the K-1, designed to service a wide range of space missions. Kistler is fabricating a fleet of fully reusable K-1 vehicles that will provide customers with reliable and flexible launch capabilities at a competitive price. Kistler is an entirely commercial program with no government funding.

Under the current leadership of Robert Wang and Dr. George E. Mueller, Kistler has assembled a team of aerospace experts and space program managers to design the K-1 vehicle and to manage the K-1 program. The design team members have collectively guided most of America's major space programs, including Redstone, Mercury, Gemini, Saturn, Skylab, Apollo, the U.S. Space Shuttle and the International Space Station. These experts also have extensive commercial space program experience.

Kistler is leading the K-1 systems engineering and integration through an integrated team composed of Kistler and contractor personnel. Each of Kistler Aerospace's contractors is a leader in its respective field of the aerospace industry and has significant experience in the construction of similar components. This team consists of Lockheed Martin Michoud Space Systems, Northrop Grumman Corporation, Aerojet, Draper Laboratory, Honeywell, Irvin Aerospace, Inc, and Oceaneering Thermal 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 in LEO. 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, significantly lower than the price of expendable launch vehicles with similar performance capability. The K-1 can also service payloads to geosynchronous transfer orbit or geosynchronous orbit with the addition of an "Active Dispenser." Kistler believes its use of existing technology and reusable modular components will enable the K-1 to achieve an operating cost not attainable by current expendable launch vehicle providers.

The K-1 Vehicle

The K-1 reusable aerospace vehicle, shown in Figure 1, has two stages. The overall vehicle is 36.9 m (121 ft) long and weighs 382,300 kg (841,000 lbs) at liftoff. The first stage, or Launch Assist Platform (LAP) is 18.3 m (60 ft) long, 6.7 m (22 ft) in diameter, and weighs 250,500 kg (551,000 lbs) at launch. The second stage, or Orbital Vehicle (OV) is 18.6 m (61 ft) long, has a cylindrical diameter of 4.3 m (14 ft), and weighs 131,800 kg (290,000 lbs) fully-fueled. Each stage carries its own suite of redundant avionics and operates autonomously.

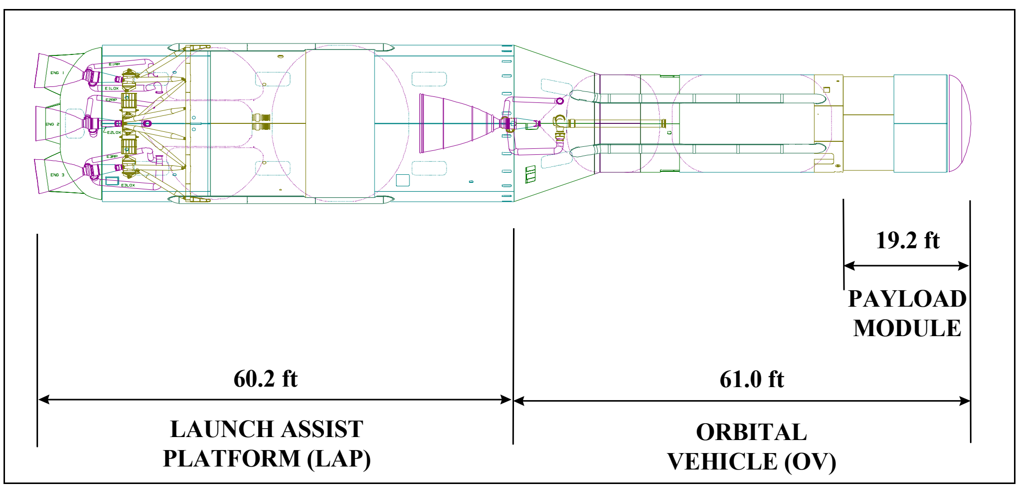

Figure 1. Profile of the K-1 Vehicle

Mission Profile

The LAP has three main engines utilizing LOX and kerosene propellants. Figure 2 shows a typical flight profile for the K-1.

Following stage separation at approximately 43 km, the LAP reorients itself and restarts its center engine to return the stage to the launch site. The LAP lands near the launch site using parachutes and airbags.

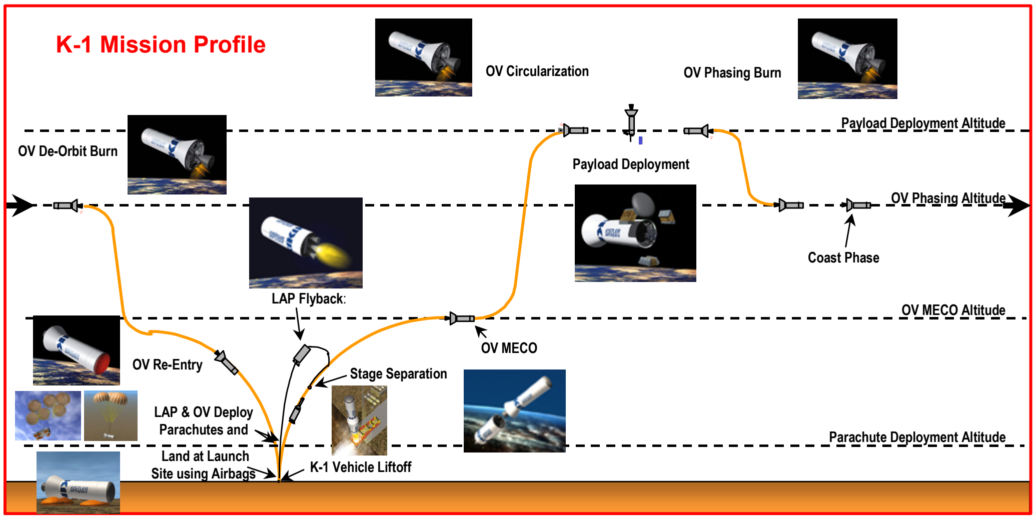

Figure 2. K-1 Typical Mission Profile

The OV ignites a single engine utilizing LOX and kerosene propellant following stage separation. The OV uses an Orbital Maneuvering System (OMS) engine for circularization, phasing, deorbit, and collision avoidance burns. The Payload Module is attached to the top of the Orbital Vehicle, containing the payload and dispenser. Every part of the Payload Module and dispenser returns intact.

After deploying its payload, the OV coasts for approximately 22 hours before returning to the launch site using parachutes and airbags.

K-1 Launch Sites

Kistler has selected two sites from which it will launch and land its K-1 vehicles: (i) the Spaceport Woomera site in South Australia, and (ii) the Nevada Test Site. The locations and initial launch corridors of each site are shown in Figure 4 and Figure 4. Kistler selected Spaceport Woomera and Nevada because the K-1 flight profile dictates launch and landing over land and this is achievable most safely from a remote area with low population density and with the necessary available infrastructure.

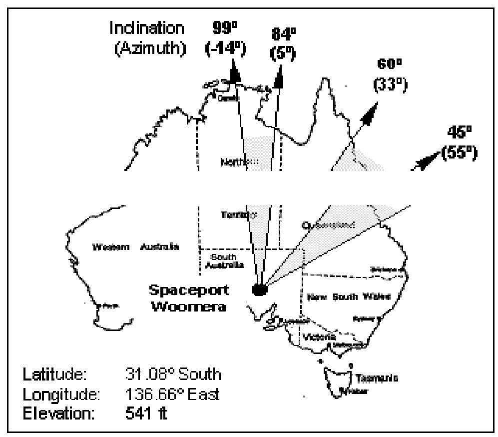

Figure 3: Spaceport Woomera Launch Site

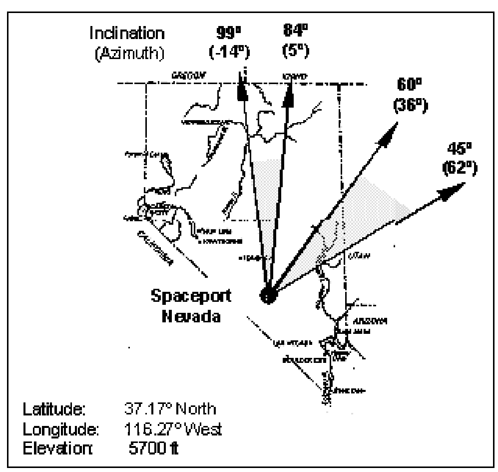

Figure 4. Spaceport Nevada Launch Site

On August 28, 1998, the Australian Department of Industry, Science and Tourism and Department of Defence executed the Operations Agreement authorizing Kistler to use the Woomera Prohibited Area for construction and operation of a launch facility, set the terms and conditions for those activities, and established a framework and procedures for launch licensing and launch operations. A groundbreaking of facilities at the Australia Site was on July 23, 1998. The Spaceport Woomera site design is complete and site permits have been obtained. Kistler plans to begin construction of the Nevada Site after successful demonstration of K-1 flight operations in Australia.

Payload Modules

The K-1 offers tow sizes of payload modules, a Standard Payload Module (SPM) and an Extended Payload Module (EPM), depending on satellite requirements. Figure 5 shows the useable dynamic envelope in these two modules.

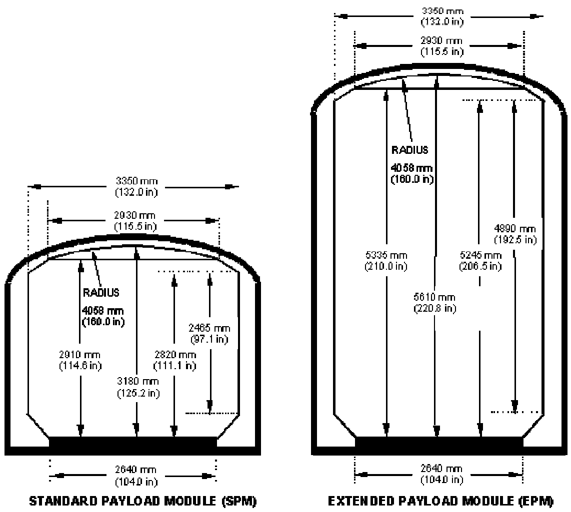

Figure 5. K-1 Payload Modules

Performance

Figure 6 shows the performance of the K-1 vehicle from its Spaceport Woomera launch site.

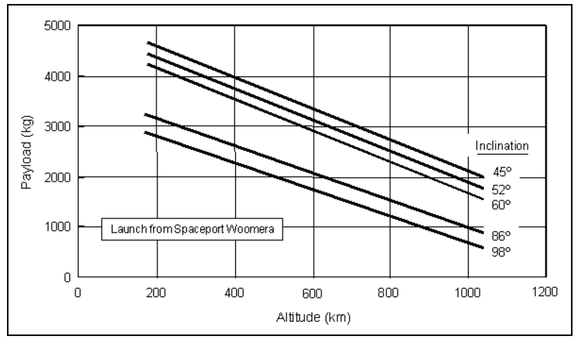

Figure 6. Circular Orbit Performance

Progress to Date

Kistler has made substantial progress toward the development of the K-1 vehicle and expects to commence test flights in the near future from Woomera, Australia, 11 months after completion of full financing. Efforts to raise the final round of financing are well underway. To date, 75% of the vehicle is complete by weight, and all the K-1's guidance, navigation, and control software is complete. Commercial operations will commence following the flight test program. Kistler has raised over $500 million in private capital and has entered into a contract with Space Systems/Loral for ten launches. Kistler has also fully insured its flight test program for the replacement value of the K-1 vehicle through a global consortium of underwriters.

Figure 7. NK-33 Engine Test Firing

More information on the K-1 vehicle, including interfaces and payload environments, can be found in the *K-1 Payload User's Guide*, available on Kistler's website at www.kistleraerospace.com. Hard copies are available upon request. Launch environments and interfaces are similar to those found in most expendable launch vehicles.

Figure 8: Six Parachute Cluster Drop Test of First Stage Return

The Astrium Multiple Payload Adapter System

Astrium has two principle designs for K-1 reusable small payload dispensers, designated MPAS-1 and MPAS-2. Astrium's MPAS designs borrow heavily on the heritage of the ASAP system.

The MPAS-1

The MPAS-1 is designed to deploy up to three base mounted minisatellites (< 500 kg each). Figure 9 displays the basic MPAS-1 structure.

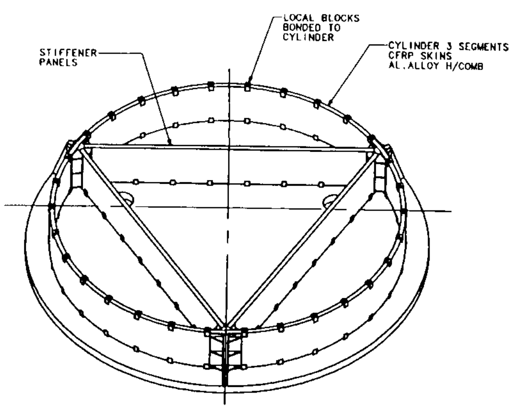

Figure 9: MPAS-1 Structure

The structure is composed of carbon-fiber reinforced plastic (CFRP) skins bonded over an aluminum alloy honeycomb core. Panels are added for additional lateral stiffness. The MPAS-1 is bolted into the standard K-1 dispenser attachment ring using 30 evenly attached bolts. It returns with the OV for reuse.

Figure 10 shows the nominal dimensions for each minisatellite. The maximum diameter of each satellite is 1.30 meters. The maximum height of each spacecraft is on the order of 2.5 meters in the Standard Payload Module. Using the Extended Payload Module would increase maximum height by approximately 2.4 meters with some loss in payload performance.

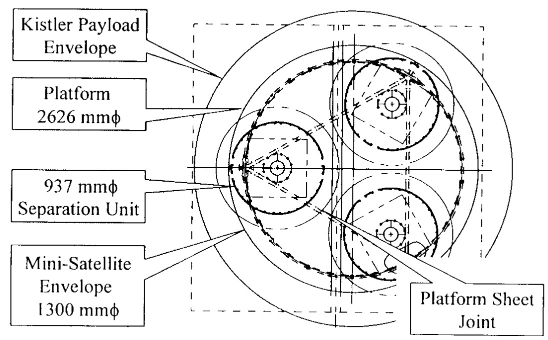

Figure 10: MPAS-1 Satellite Envelope

The standard mechanical interface is a 937 mm marmon clamp separation unit. Flanges of other diameters or bolted separation units can be accommodated with a retrofit as a non-standard service. The three minisatellites will share the K-1 payload umbilical up until lift-off. This umbilical, which passes through the OV and into the Launch Terminal Room, consists of eighty-four 16-guage wires for payload telemetry, command, and control. Telemetry and command links during launch can accommodated as a non-standard service.

After delivery to the desired orbit and separation, the customer will receive a separation indication from the OV through the Tracking and Data Relay Satellite (TDRS), as well as a state vector just prior to separation.

The MPAS-2

While the MPAS-1 is designed to fly minisatellites on a dedicated mission, the MPAS-2 is designed primarily to fly microsatellites (<125 kg) as secondary payloads. The MPAS-2 may also be used to fly dedicated microsatellite missions, however. Figure 11 displays the MPAS-2 structure.

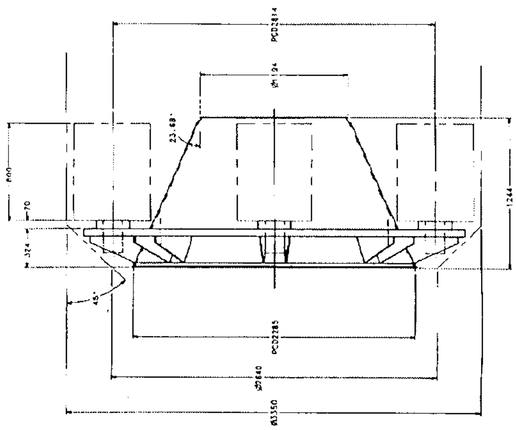

Figure 11: MPAS-2 Structure

The MPAS-2 is an annular platform of CFRP/aluminum honeycomb, mounted with brackets to the base of the primary payload's moncoque CFRP adapter cone. There are eight positions for microsatellites on the platform. Each microsatellite is contained within an envelope 800 mm high and a square cross-section 618 mm on each side.

The standard satellite attachment and separation system has not been selected, but may be similar to the Surrey Satellite Technology Ltd (SSTL) microsatellite separation system. This is a 9" Marmon clampband with two pyrotechnic cutters and a single coiled spring for push-off. It would attach to the annular platform with 12 M6 inserts. The platform would have a 150 mm diameter central hole at each microsatellite position to accommodate the tip of a stabilization boom. Other separation systems would be accommodated if desired by the customer as a non-standard service.

The adapter cone for the primary payload can accommodate 937 mm and 1194 mm interfaces. Each cone will have a common cone angle. Figure 12 and Figure 13 show the available volume for the primary payload using the 1194 mm interface for both the SPM and EPM.

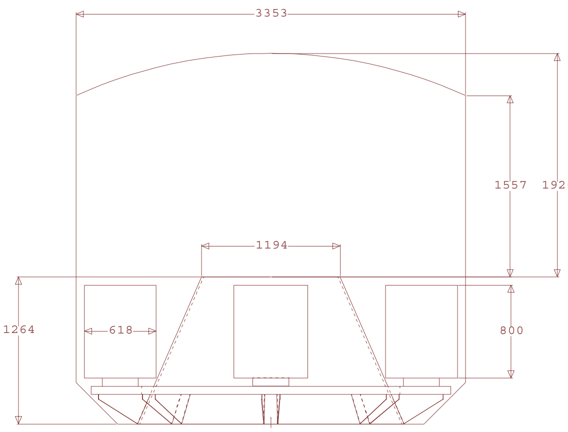

Figure 12: Volume in SPM with MPAS-2

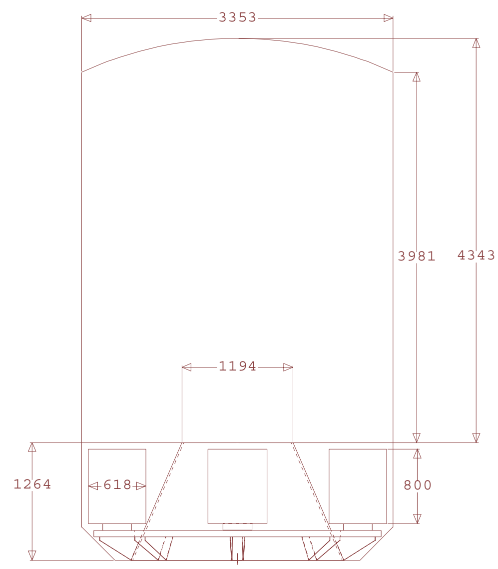

Figure 13: Volume in EPM with MPAS-2

Nominally, the K-1 ground payload umbilical will be dedicated to the primary payload, with no electrical interface for the microsatellites during encapsulation. For dedicated microsatellite missions, or for missions where the primary payload will not make use of the entire umbilical's capacity, other accommodations can be arranged. All customers will receive a separation indication and state vector at the time of separation through the OV TDRS downlink.

Ticket-to-Orbit

Kistler wishes to offer small satellites expanded opportunities to access space. Many of these opportunities are expected to arise when excess margin is identified on a mission and a primary payload customer is receptive to the inclusion of a secondary payload. These opportunities may also arise through regularly scheduled, dedicated small satellite launches to popular orbits on which customers purchase “tickets” for slots on the dispenser, rather than an entire launch.

Ticket-to-Orbit Destinations

Ticket-to-Orbit would consist of regular K-1 missions to orbits often selected by mission designers. One potential example is a sun-synchronous orbit, with an altitude between 600 to 800 km, a highly desirous orbit for remote sensing missions. The orbit selected would be based on an assessment of market demand.

Initial Announcement of Opportunity

Well before the intended launch date, Kistler would issue an initial Announcement of Opportunity to the small satellite community, declaring the approximate mission orbit and approximate launch date. Kistler may market these launches through a broker (such as Space Operations International) or through other channels, such as the NASA Access to Space website (http://accesstospace.nasa.gov/). The Announcement would include basic information on range of standard interfaces and anticipated flight environments for the spacecraft. The Announcement would also include ROM prices for a standard set of services. Potential customers responding to this announcement would be asked to complete a brief Payload Questionnaire specifying basic mission requirements and interfaces.

The purpose of this first announcement will be to assess the market demand for such a service and to gather basic technical requirements. Kistler hopes this announcement will also stimulate demand. Knowing the approximate date a low-cost launch service will be offered well ahead of time may be useful for spacecraft designers to adjust their development schedules. Through the price elasticity of demand, it may even stimulate new missions, both commercial and government, that would otherwise not have materialized without this opportunity. To extend the airline comparison, this would be analogous to the influx of spur-of-the-moment travelers that airlines see when they cut their rates for a limited time.

Second Announcement of Opportunity

If the first Announcement generates sufficient interest, several months later, Kistler would issue a formal, second Announcement of Opportunity for the mission. The Announcement would include fixed prices for a standard set of services, plus prices for some non-standard services. It would also include information on the dispenser and interfaces to be available on the mission. For example, if the initial Announcement generated interest from different developers of two minisatellites, then Kistler may select the MPAS-1. If, on the other hand, the Announcement generated interest from several microsatellite operators, Kistler may select the MPAS-2. Kistler may also select another small payload adapter from a different manufacturer aside from the MPAS, depending on the mission. At this point, Kistler would be ready to sign launch contracts with individual customers for spaces on the dispenser.

Small Payload Transfer Vehicle Option

There will be instances when the orbital requirements of spacecraft that want to fly on such a mission are close, but do not match perfectly. A number of payloads may desire launch to a sun synchronous orbit, for example, but their desired altitude may vary substantially. For these payloads, a number of innovative companies are developing orbital transfer stages especially for small payloads. These stages have delta-v capabilities on the order of several hundred meters per second. They can be used for large altitude changes within LEO, small plane changes, or for phasing to different nodal crossing times. Some of these stages are expected to be compatible with the interfaces discussed in this paper. Kistler may team with companies developing these stages, and offer them to customers as a non-standard service. Customers are also free to purchase these stages themselves, or build propulsive transfer capability into their vehicles themselves.

Mission Integration

After entering into a launch contract, the work of mission integration can begin. The *K-1 Payload User’s Guide*, published in May 1999 and available at www.kistleraerospace.com, details Kistler Aerospace

Corporation's streamlined approach to mission management and documentation. As part of its standard service, Kistler would include the following integrated mission analyses:

- Trajectory
- Separation
- Coupled Loads
- Clearance
- Thermal
- Acoustic
- Fairing Pressure Transient
- RF/EMI/EMC Compatibility.

On the customer side, Kistler will specify required testing and verification activities, including:

- Factors of Safety for tests
- Static tests
- Acoustic tests
- Vibration test
- Fit check
- Shock test.

Kistler and the customers will develop an Interface Control Document and a Launch Operations Plan to ensure effective integration. The actual organization performing the launch site processing will depend on the nature of the mission and the requirements of the payload. Kistler, the individual payload customers, an outside contractor, or a combination may be involved in the processing.

Regularly Scheduled Departures

Kistler hopes the Ticket-to-Orbit concept will be successful enough for Kistler to offer flights to specific orbits on specific, regularly scheduled dates. The frequency of flight will depend on an assessment of demand for the orbit. This will enable mission designers to know about launch opportunities for low-cost, small payload missions well in advance. Programs that cannot meet a launch date one year can wait for a subsequent year. Kistler hopes satellite designers will find these opportunities so valuable that they will build their buses especially to fit the Kistler interface and envelope.

Pricing Strategy

Kistler will offer Ticket-to-Orbit customers launch in a dispenser slot with a standard interface and set of services for a fixed price. The price for each slot will depend on the mission orbit and payload capability of the K-1 to that orbit. Kistler has published a list price of $17 M per K-1 launch for a dedicated LEO mission. Kistler will price Ticket-to-Orbit slots so as to recover this price *on missions utilizing an average (not full) payload capacity*, with competitive rates.

Ticket-to-Orbit Announcement Schedule

Kistler expects to issue the first of a series of Initial Announcement of Opportunities for Ticket-to-Orbit small satellite missions shortly after securing full-financing. Opportunities exist for small payloads to fly on the second flight test and on early manifest flights once full commercial operations commence. Kistler is participating in NASA's Next Generation Launch Services Acquisition (NGLS) to fly small satellites and technology demonstration missions on emerging launch vehicles, and opportunities may exist for secondary payloads on these flights. Kistler is also discussing a mission with the Air Force that would have excess margin for secondary payloads. In short, many low-cost launch opportunities will exist for small satellites on the K-1, and Kistler plans to make the first Initial Announcements of Opportunity in the near future.

Conclusion

Kistler Aerospace Corporation is building the K-1, the world's first fully-reusable aerospace vehicle. The K-1 will offer customers low-cost, flexible access to space. Astrium Ltd., in partnership with Kistler, will provide multiple small payload adapters for use on the K-1. These adapters can be used for secondary payloads, or for dedicated small payload missions.

Leveraging the K-1's reusability and low-cost, Kistler is developing a concept for regularly-scheduled dedicated small payload missions called Ticket-to-Orbit. On Ticket-to-Orbit missions, Kistler will sell slots on a dispenser at a fixed price for a standard set of services, rather than an entire launch to a single customer. This strategy will *proactively* create ridesharing opportunities in the mission planning phase of a satellite program, rather than forcing customers to find rideshare opportunities after they develop their mission concepts.