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The XP Spaceplane: A Multi-role Suborbital Reusable Launch Vehicle for Space Testing and Microgravity Science Applications

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The XP spaceplane is a six seat business jet sized horizontal takeoff and landing vehicle designed primarily to service the emerging suborbital space tourism market. Following a week of training and orientation to the spaceflight experience, the five passengers and their pilot would experience a one hour suborbital space flight with 3 – 4 G's of acceleration / deceleration force; with about 3 to 4 minutes of weightlessness as the vehicle coasts over the 100 km apogee and back to atmospheric reencounter. This same flight profile has a variety of non-tourist space flight applications which can also benefit from the low cost, frequent and user-friendly access to space and the microgravity environment. Moreover, the high flight rate capability inherent in the XP spaceplane design means that a full market penetration in the tourism market will still leave ample flight capability for other types of space flight services described in this paper.

Key Words: Suborbital Space Flight, Microgravity Research, Astronomy, Remote Sensing, Flight Tests,

1. Introduction

In the 50 years of the Space Age, less than 500 people have traveled to space – either making orbit or traveling on a suborbital space trajectory. Beginning in 2010, Rocketplane and several other competitors are expected to begin suborbital commercial space flight services in the US. Over the next five years, thousands of private citizens will earn their astronaut wings by flying with one or more of the emerging commercial space flight companies. The vehicles designed to safely and routinely perform human suborbital space flight also have several compelling advantages for utilization by the microgravity science community, the remote sensing industry, and for microsatellite launch and extremely high altitude sound rocket applications.

Figure 1. The XP spaceplane on ascent

The XP spaceplane cabin seats six people - one pilot and five passengers. A unique feature of the Rocketplane vehicle is that one of the passengers gets to enjoy a "premium seat" flight experience sitting in the front right seat next to the pilot. This experience is rare even among government astronauts flying in the Shuttle, most of which sit in the back or below in the mid-deck area. The view out the front windscreen will be truly spectacular. This seat also is equipped with a extra-large LCD display tied to the onboard flight data and video systems. In effect this is a personal computer workstation for this passenger flight station, and thus become the Payload Specialist / Science Officer flight station when the XP cabin is configured for research flights rather than pure passenger flights.

For research flights the second and third row of seats are removed and an equipment rack structure is fastened to the seat attachment rails and upper structural support rails. The cabin volume created in this configuration is approximately the same volume as in a US minivan with the second and third rows of seats stowed or removed. The equipment rack structure installed for a multi-user science flight can accommodate twelve standard ISS single mid-deck locker payloads, or four double mid-deck locker payloads and four single mid-deck locker payloads. Custom payload configurations are also possible.

The equipment rack is designed to emulate exactly the interfaces found in an ISS Express Rack. In addition to emulating the structural interfaces, power, data, communications, cooling air, chilled water and process gases which are available resources on the ISS can all be made available to the payloads installed in the XP science rack structure. The total internal payload capacity is equal to 1.5 standard ISS Express Racks.

2. The XP Flight Profile

The XP spaceplane takes off and lands much like a conventional business jet, except that the jet engines use afterburning turbojets to increase takeoff thrust and shorten takeoff roll. The vehicle makes a steady climb under jet power to over 40,000' altitude while flying about 80 miles downrange from the spaceport to position the vehicle for the rocket powered ascent to space. Once at the ignition coordinates, the XP makes a 180º heading change to point back towards the runway at the spaceport, then the pilot begins the rocket engine ignition sequence. In less than two seconds the rocket engine is at full thrust. After successful ignition and confirmation of vehicle health status, the pilot pulls back on the stick to a 70º nose-up attitude and begins the zoom climb to space. Initial G forces are about 2 G's in the X axis at ignition and then a 3G load in the Y axis during the rotation to the ascent attitude is experienced X axis G forces build up to a peak of over 3 G's as acceleration increases as the fuel is consumed and the vehicle gets lighter.

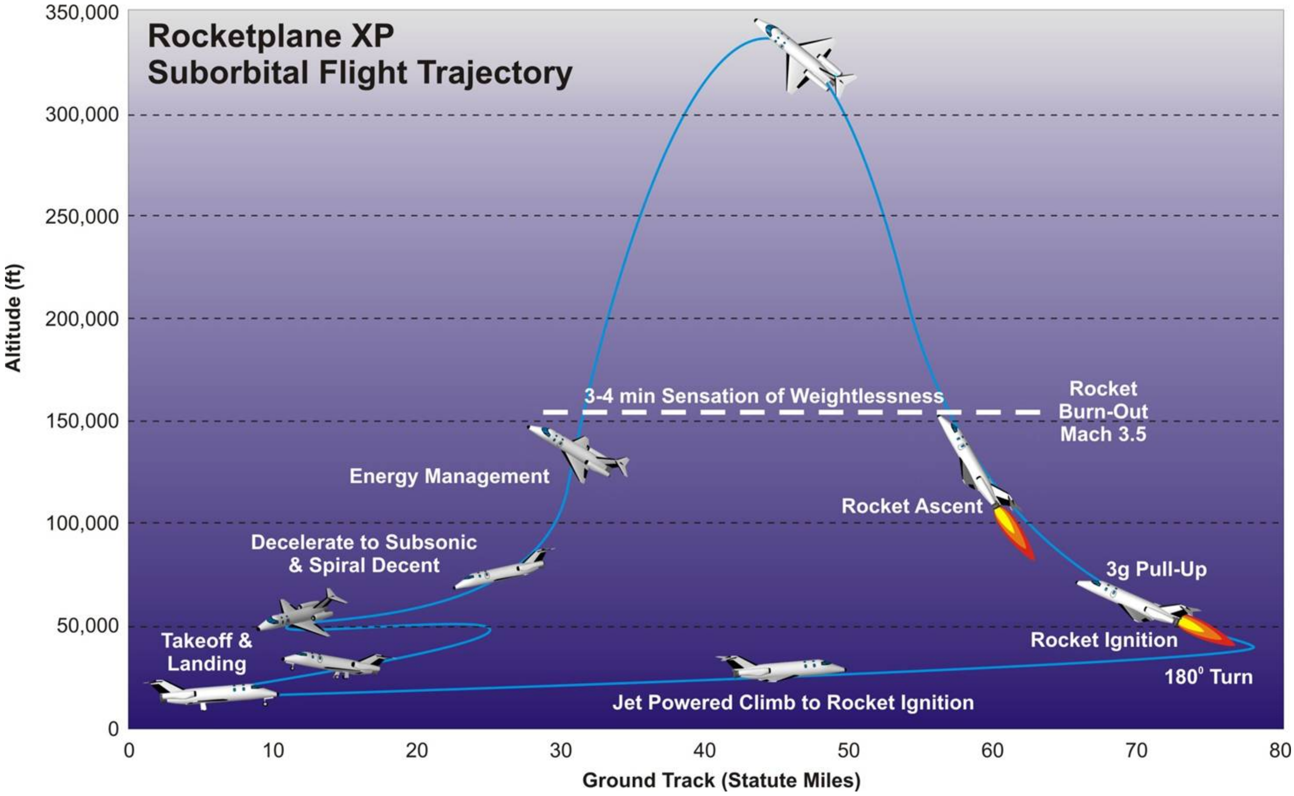


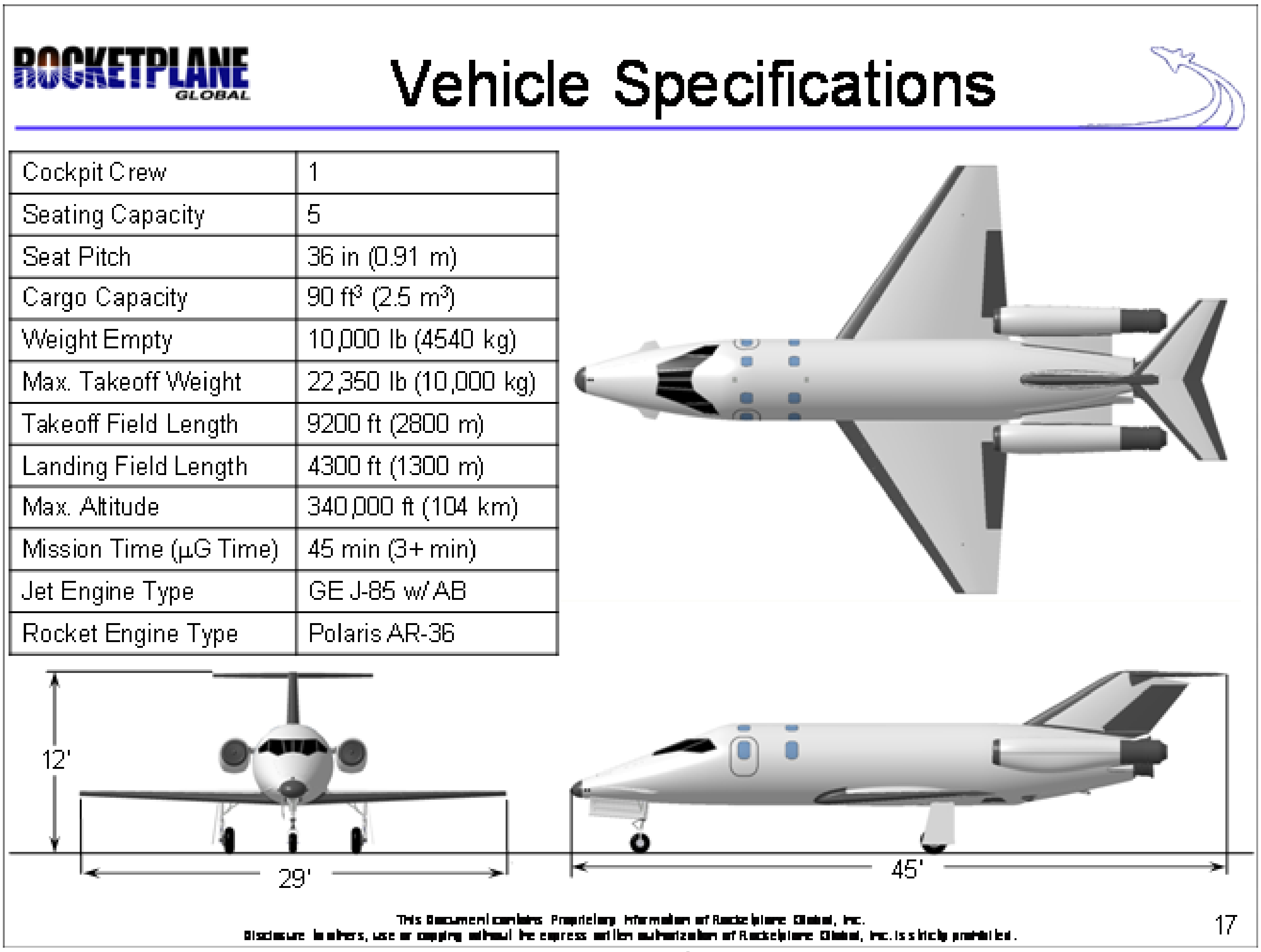
Figure 2. XP Flight Profile

In less than 90 seconds more than 10,000 pounds of liquid oxygen and kerosene rocket fuel have been consumed and the rocket engine shuts down. As soon as the rocket engine is shut down the weightlessness phase of the flight profile begins. For research flights where the goal is to maximize the duration of continuous high quality microgravity as discussed in this paper, the pilot immediately uses the peroxide monopropellant thrusters in the nose to orient the spaceplane from its nose-up attitude to the proper nose-down attitude needed for re-entry. As soon as this RCS pitch maneuver is completed, the pilot will stay off the stick and let the vehicle perform its coast to the top of the 100 km+ apogee and begin the fall back to Earth in its inertial attitude. With no RCS forces and the on-board crew sitting quietly to minimize vibrations, it is expected that the quality of the microgravity environment during the coast phase should be between the 10^{-4} and 10^{-5} G level, which is comparable to the microgravity environment aboard the International Space Station (ISS) during normal operations.

When the suborbital flight path reaches about 150,000' on the descent phase, the vehicle begins to reencounter the upper atmosphere and decelerate. Over about a minute the G forces of the reentry deceleration build to a peak of about 4 G's, then fall off as the XP begins its glide phase on the return back to the spaceport. The spaceplane transitions to subsonic at about 50,000' altitude. At 20,000' an air start procedure is initiated on one of the jet engines to provide extra throttle power to the pilot to manage the approach and landing back at the spaceport. With proper energy management of the reentry glide, there should be enough jet fuel remaining in the wing tanks to be able to perform a once-around maneuver on final approach in the event of a runway incursion or other unexpected landing event. Total flight time from takeoff to touchdown is about 45 minutes.

The principal difference between the flight profile of a passenger flight and a research flight is the use of the RCS thrusters during the coast phase. Passengers will want to maximize the Earth views during the weightless apogee phase of the flight, so the vehicle will perform more RCS roll and pitch firings to provide panoramic vistas across the front and side windows. For a microgravity research flight, the views are irrelevant, so the RCS maneuver to the proper reentry attitude happens immediately and the forward view stays "nose-down" for the duration of the apogee coast. The pilot and flight engineer or science officer sitting in the front of the spaceplane will still enjoy a rare and spectacular view that only a few of even the Shuttle astronauts have ever experienced, but that is not the primary purpose of the mission.


Figure 3. XP spaceplane at apogee



Cockpit Crew	1
Seating Capacity	5
Seat Pitch	36 in (0.91 m)
Cargo Capacity	90 ft³ (2.5 m³)
Weight Empty	10,000 lb (4540 kg)
Max. Takeoff Weight	22,350 lb (10,000 kg)
Takeoff Field Length	9200 ft (2800 m)
Landing Field Length	4300 ft (1300 m)
Max. Altitude	340,000 ft (104 km)
Mission Time (µG Time)	45 min (3+ min)
Jet Engine Type	GE J-85 w/ AB
Rocket Engine Type	Polaris AR-36

Figure 4. XP 3 view diagram

3. Microgravity Research Payload Accommodations

The pressurized cabin and benign G loads of the XP are analogous to those found on the Space Shuttle. It is expected that most microgravity science and research payloads will elect to use the standard payload interfaces and modules found on the Shuttle and ISS, specifically the mid-deck locker (MDL) payloads found in an ISS Express Rack. By emulating the current standard payload interfaces found on the ISS, the XP can become a testing and flight qualification vehicle for payloads designed for long duration microgravity missions. A Principal Investigator developing an ISS research payloads will typically spend years of time and millions of dollars in staff cost and hardware development, fabrication, testing and qualification expenses prior to actually getting the payload manifested for flight. The XP flight profile is an almost exact match to the flight profiles found on the Shuttle and on the new HTV and ATV vehicles that will deliver these payloads to the ISS. Peak G loads are around 3.5 G's axial on ascent and about 4 G's normal on reentry, while the shirtsleeve environment pressurized cabin mimics the conditions found in any of the ISS laboratory modules. This flight envelope thus provides an ideal testing environment for ISS payloads to verify that all payload systems can function within the G loads and vibroacoustics environment of launch and still function properly in the microgravity environment. A payload developer who has millions of dollars invested in a payload will be very motivated to perform such flight tests when the total cost of each mid-deck locker test flight is on the order of $100,000.

For some microgravity science applications such as fluid physics and combustion, meaningful experiment results can be obtained in the 3 minutes of microgravity time available, and there is no need to "graduate" the payloads to the ISS for longer duration microgravity. Some materials science and life sciences applications including mouse experiments can also obtain meaningful results in this time, and thus become long-term repeat customers for flying lots of suborbital missions rather than spending their entire budget on a single ISS flight every five years or so. This new flight capability is expected expand the market for microgravity research significantly.

NASA and Space Florida have in place a Microgravity Life Sciences Laboratory at Kennedy Space Center, and they are actively promoting university and commercial microgravity research opportunities in suborbital vehicles. KSC / Space Florida is developing the FastRack system to be installed in a variety of suborbital vehicles as a modular approach to supporting MDL payload suborbital flights. The concept is to have a rack structure that can carry two single or one double MDL that can be installed in place of a single passenger seat. The structural and life support load requirements are surprisingly similar, with both a passenger plus seat and a rack plus lockers weighing almost exactly the same and requiring a similar amount of cooling, power and life support functions. Each rack would carry its own supplemental batteries, gas bottles and other utilities so that the structural interface and the resources available to a MDL payload would be identical to those found in a standard ISS Express Rack. This feature provides the added benefit of not requiring the payload developer to design and configure different experiment payloads for different vehicles. A diagram of the FastRack is shown in Figure 4 below.

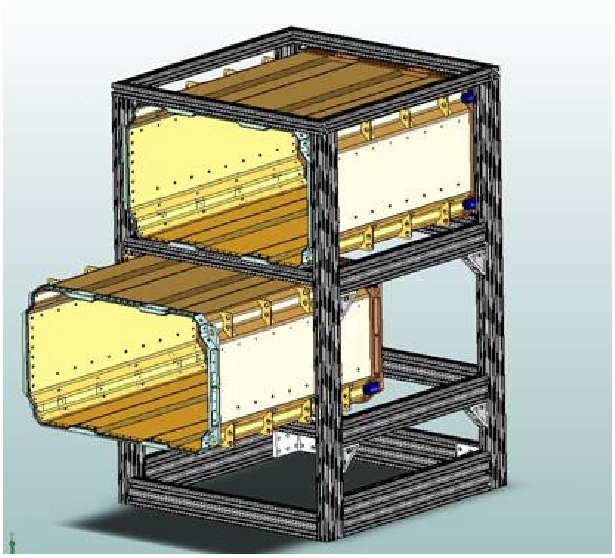


Figure 5. NASA FastRack MDL Payload Accommodation

Using the modular FastRack system, an XP research flight could carry up to eight MDL payloads. It will also be possible to configure the cabin for "combi" flights where two or three Payload Specialist astronauts or commercial Principal Investigators could fly with their payloads and actively manage their microgravity payloads. The XP will be equipped with high-bandwidth communications capability and multi-channel HD video downlinks, so it is also possible to payloads to be actively controlled from the ground in the Mission Control Center.

If the demand for this class of MDL microgravity payload flight services turns out to be strong, a full-cabin rack for the XP can be developed which maximizes the number of payloads on each flight by filling the entire second and third row seat cabin volume with a large rack that can hold up to 12 MDL payloads. This rack configuration is shown in Figure 5. The right front seat would still be available for a single Payload Specialist / Science Officer to fly to manage the payload systems.

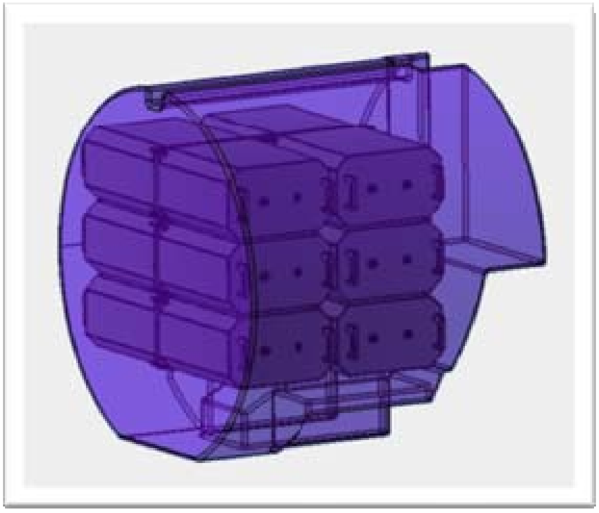


Figure 6. Full Cabin MDL Payload Rack Accommodation

The right front seat will have its own large LCD multi-function display screen and cursor controls built into the arm rest of the seat, so the Flight Engineer or Science Officer will in effect have their own PC built in to the instrument panel for controlling experiments or payloads installed in the cabin. Standard internet protocols and digital video signal feeds will be built in to the XP data bus, and a high capacity solid state data storage bank will also be included in the cabin equipment. Payload developers may choose to use these on-board resources or fly payloads with autonomous resources and data recording at their discretion. The pilot and Flight Engineer control stations are shown in Figure 6 below.

Figure 7. Pilot and Flight Engineer stations

4. Remote Sensing & Astronomy Missions

One additional category of missions for the XP is to use the 100 km vantage point at apogee for observation and image gathering. The spaceplane will be equipped with an external centerline payload mounting rail on the belly of the vehicle. This payload mount can be used for the release of an expendable upper stage for microsatellite launch (discussed below) or a sensor / image gathering pod which remains on the vehicle throughout the flight. For terrestrial observations, multi-spectral optical, SAR or LIDAR pods could be mounted in this location and the control and data recording equipment can be installed inside the cabin in rack accommodations as described above.

From 100 km altitude it is possible to see 1,000 km in any direction, giving a total viewshed area of over 3 million square km. Depending on the nature of the remote sensing or image gathering mission, a wide area can be swept at a lower resolution or a narrower field of view can be scanned at a much higher level of resolution. Different spectral bands can be scanned simultaneously or even combinations of optical and SAR / LIDAR data can be gathered. Resource management and agricultural monitoring applications need precise lighting, growing condition timing and lack of cloud cover to obtain data, and existing satellite-based imagery providers often cannot capture this data exactly as the customer wants it. A suborbital remote sensing / reconnaissance vehicle can sit on the runway waiting for optimum conditions, and only fly when capturing the requested images can be assured. This “just-in-time” image gathering capability is an entirely new class of service, and should be of interest to both civil and governmental customers.

5. Microsatellite Launch

The XP spaceplane can also be used as the reusable first stage of a multi-stage satellite launch vehicle architecture for the independent launching of small satellites to Low Earth Orbit. At the present there is now way to affordably launch just one satellite in the 10 kg to 100 kg class. Instead they must be clustered into a larger rocket, or wait for secondary payload launch opportunities as a “hitchhiker” to a large communications or science satellite.

The flight profile for a satellite launch would be identical through rocket engine cutoff. Immediately after engine shutdown, the upper stage package and payload would be released in a gentle low Q environment and the fire command would be sent to the upper stage. This launch is depicted in Figure 7.


Figure 8. XP Microsatellite Launch

A variety of upper stages can be used for this mission. Conventional ATK STAR 20 motors have been used for this type of launch in the US for many years. Two or three of these motors can be stacked in this upper stage assembly depicted above. Another option is to use a new generation high performance hybrid upper stage rocket developed in Hokkaido by CAMUI Space Works. A companion paper on the CAMUI development effort is presented in another ISTS session. A CAD view of the XP with an upper stage mounted on the launch rail is shown on Figure 8 below.


Figure 9. XP with CAMUI Upper Stage Rocket

XP ORS		Upper Stage
Small Sat	~25-50kg 100km	

This category of launch service does not presently exist, but is of interest in the US under the Operationally Responsive Spacelift programs of the Department of Defense. Both government and commercial customers would benefit from affordable and flexible launch services for small satellite payloads. Commercial prices for this type of “one-shot” microsatellite launch could be less than $1 million depending on size, quantity of launches and the desired orbits. By flying the launch profile from a conventional runway takeoff, any launch azimuth can be serviced from a selection of spaceports around the world.

6. Conclusion

Reusable launch vehicles benefit significantly from high flight rates and diversification of markets. While the base load market for suborbital flight is expected to be passenger tourist service, the non-tourist markets discussed in this paper could make up a significant fraction of the total annual flight manifest for suborbital spaceplanes. The XP is designed to be capable of routine 24 hour vehicle turnaround, so each spaceplane has a potential to fly more than 300 times per year. There is not currently any single demonstrated market than can absorb this much flight capacity, much less the combined lift capacity of a fleet of six or more XP spaceplanes and it competitors. New markets and new operating methods are needed to fully utilize this dramatically lower and more available space access for customers of all types.