The Falcon 1 Flight-003 Jumpstart Mission Integration Summary

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ABSTRACT

In 2007, following Demonstration Flight 2 - Falcon 1's second demonstration mission, SpaceX declared Falcon 1 ready to exit the demonstration program and upgraded the vehicle to operational status. The mission was sponsored by the Defense Advanced Research Projects Agency (DARPA) and the US Air Force (USAF) with objectives centered on testing the vehicle in flight, gathering data and retiring technical risk prior to the first operational flight. This flight resulted in retiring significant risks in both the ground and flight systems. A review of the successes and achievements which led to the decision to go operational is presented along with a description of the interim upgrades made to the vehicle in support of subsequent missions.

In 2008, the Jumpstart Mission will be the third flight of the Falcon 1 launch vehicle developed by Space Exploration Technologies in Hawthorne, CA. There are two primary customers for this mission; one is the Department of Defense's Operationally Responsive Space (ORS) Office and the other is ATSB® of Malaysia. A high-level overview of this mission is discussed along with the future plans for the Falcon 1 launch vehicle, including an additional Falcon 1 mission manifested for 2008 and two others in 2009. Additionally, to better service the needs of the small satellite community, SpaceX plans to upgrade to the Falcon 1 launch vehicle. Beginning in 2010, the enhanced Falcon 1 (Falcon 1e, F1e) will become SpaceX's standard small launch vehicle. An overview of these changes and how they will positively impact the small satellite community are discussed.

FALCON 1 LAUNCH VEHICLE

The Falcon 1 is designed to provide the world's lowest cost access to orbit. The vehicle was designed above all for high reliability, followed by low cost and a benign payload flight environment.

Overview

The Falcon 1 is approximately 70' in height with a Gross Lift-Off Weight (GLOW) of about 62,000 lbm. It is a two-stage, liquid oxygen (LOX) and rocket-grade kerosene (RP-1) powered launch vehicle which combines a turbopump-fed first stage powered by a SpaceX developed Merlin engine with a pressure-fed second stage powered by a SpaceX developed Kestrel engine.

The first stage of the Falcon 1 generates 78,400 lbf (349 kN) of sea-level thrust using a single Merlin engine. The Merlin rocket engine, shown in Figure 1, was designed and developed internally at SpaceX. Like the rest of the Falcon 1, the Merlin was designed for high reliability and low cost. This was achieved by keeping the design as simple as possible and drawing on a long heritage of space-proven engines. The Merlin engine has demonstrated large margins in heat flux, mixture ratio tolerance and turbo pump operating speed during ground testing, and has exceeded the performance goals set during the design phase.

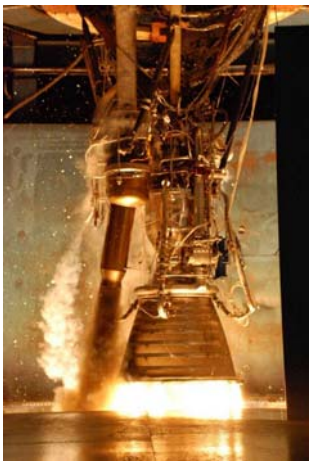

Figure 1 ***Merlin engine during test fire***

The second stage of the Falcon 1 generates 7,000 lbf (31 kN) of vacuum thrust using a single Kestrel engine, which is capable of multiple re-starts on orbit.

This vehicle was developed entirely by SpaceX under funding provided by SpaceX founder and CEO, Mr. Elon Musk.

DEMONSTRATION FLIGHT 2 MISSION OVERVIEW

Overview

On March 21, 2007 SpaceX launched the second demonstration flight of the Falcon 1 launch vehicle. The mission was sponsored by the Defense Advanced Research Projects Agency (DARPA) and the US Air Force (USAF) with objectives centered on testing the vehicle in flight, gathering data and retiring technical risk prior to the first operational flight.

This mission, Demonstration Flight 2 or "Demo 2", was the return to flight of the Falcon 1 after significant modifications following the inaugural flight.. Like the inaugural flight, this mission was launched from facilities on Omelek Island, part of Reagan Test Site (RTS) on Kwajalein Atoll in the Marshall Islands. All launch and control facilities, including the Mission Control Center, the launch pad and the vehicle and payload integration facilities were also developed entirely by SpaceX.

Figure 2 ***Falcon 1 Demo 2 Mission***

A clear majority of the Demo 2 mission technical objectives were met by this return to flight. A 2nd stage control anomaly, however, ultimately prevented the stage from reaching orbital velocity. Eight technical anomalies were identified by post-flight data analysis; though the 2nd stage control anomaly was the only issue that prevented this mission from achieving orbit. All of the anomalies have since been addressed by design and/or process changes.

Demo 2 Mission Conclusions

This mission, although short of complete success, was nonetheless a large step forward for SpaceX and the Falcon 1 launch vehicle and the DARPA/USAF Falcon Program. A significant majority of mission objectives were met from both programmatic and technical perspectives. Many significant risks were retired in each major flight domain and open issues were identified and have been addressed for future launches.

Obtaining flight data from the vehicle was a primary objective of this test flight and was clearly achieved based on both the quantity and quality of performance and environmental data. Additionally, operations concepts, procedures, ground systems and control automation systems were validated. A rapid response capability was also demonstrated with a hot-fire abort being followed within 70 minutes by a launch. Significant achievements in Operational Responsiveness for Call-up and Launch were also demonstrated.

The many successes of this mission and the large amount of flight data obtained, including on anomalous behaviors, have greatly reduced risks for all future Falcon 1 missions.

FALCON 1 CURRENT AND FUTURE UPGRADES

Overview

Due to the successes of the Demo 2 mission in retiring risks in the ground and flight systems, SpaceX declared the Falcon 1 ready to exit the demonstration program and upgraded the launch vehicle to operational status. Consistent with SpaceX's corporate philosophy of rapid and continuous improvement, Falcon 1 has a planned upgrade path based upon experience from the demonstration missions. These vehicle enhancements are being implemented as a block upgrade that will increase the payload capability beyond that of the original Falcon 1 configuration.

First Stage Upgrades

The Merlin engine employed for the first two demonstration flights of the Falcon 1 utilized an ablatively cooled thrust chamber and nozzle. To increase reliability, performance and allow for potential reuse, the chamber and nozzle have been upgraded to regeneratively cooled designs. Because it is able to operate at higher temperatures and pressures, the regeneratively cooled (Merlin 1C) design provides a greater level of thrust, upwards of 125,000 lbf of sea-level thrust.

The greater thrust of the Merlin 1C engine would exceed the structural margins of the existing Falcon 1 first stage design, which was originally qualified based on the lower thrust ablatively cooled engine. In addition, when operating at full thrust, the Merlin 1C requires an increased propellant flow rate. Therefore, the first stage tank structure will be redesigned and qualified to meet the increased load requirements and propellant needs of the new engine. This full block upgrade, called the Falcon 1e (for *enhanced*) will be available beginning in the second quarter of 2010. However, as an interim upgrade, the Merlin 1C engine will be flown at a reduced thrust level for operational launches in 2008, 2009, and early 2010.

Second Stage Upgrades

As a weight savings measure, the stage 2 tank material has been changed from 2219 to 2014 aluminum alloy. In addition, slosh baffles have been added to both the Fuel and LOX tanks to prevent further occurrences of the stage 2 control anomaly experienced during the Demo 2 mission. An illustration of the slosh baffle addition is shown in Figure 3.

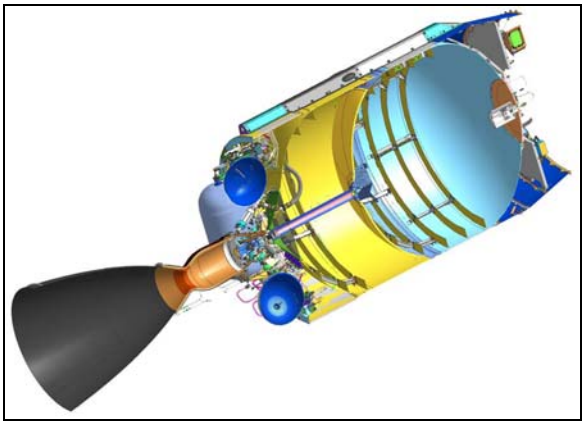

Figure 3 ***Stage 2 cross section illustrating internal slosh baffles***

Reliability improvements have been made to the Kestrel engine, which also allowed for some mass reductions. For the Falcon 1e, additional mass savings will be achieved by changing the second stage tank material to a 2195 aluminum lithium alloy.

Payload Fairing Upgrades

The Falcon 1 employs a bi-conic aluminum payload fairing with a maximum inner diameter of 54 in (1.4 m) and an internal height of 110 in (2.8 m). Minimal changes were made to the fairing assembly in preparation for the operational launches following the Demo 2 mission. For mass savings and to provide increased payload volume, the payload fairing for the

Falcon 1e will be a composite ogive with a maximum inner diameter of 61 in (1.55 m) and an internal height of 150 in (3.8 m). A dimensional comparison of the Falcon 1 and Falcon 1e payload fairings is provided in Figure 4.

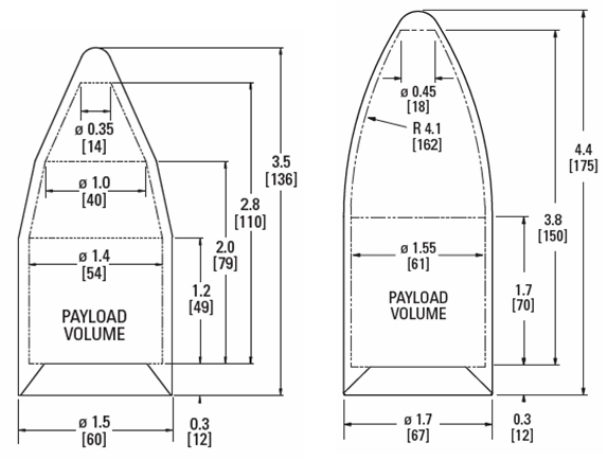

Figure 4 ***Falcon 1 and Falcon 1e payload fairing dimensions***

Falcon 1 Payload Capabilities

The Falcon 1 is capable of delivering a 925 lb (420 kg) satellite into a circular reference orbit of 185 km inclined at 9.1 degrees, as shown in **Error! Reference source not found.**. The Falcon 1e will provide the increased payload capability shown in Fig. 7; with the ability to deliver a 2,225 lb (1,010 kg) satellite into a reference orbit of 185 km inclined at 9.1 degrees.

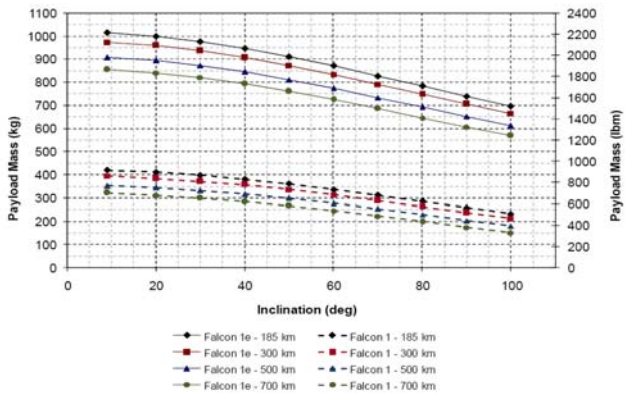

Figure 5 ***Falcon 1 and Falcon 1e payload capability***

ORS JUMPSTART MISSION OVERVIEW

Overview

Scheduled for flight in the summer of 2008 from the SpaceX launch complex in the Central Pacific Marshall Islands' Kwajalein Atoll, the ORS Jumpstart mission aims to establish a preliminary framework for responsive contracting, and to demonstrate the ability to rapidly integrate and execute a mission, from initial call-up to launch.

This ORS Office tasked SpaceX with demonstrating its ability to perform responsive mission integration for three separate candidate payloads. The actual flight payload was to be determined by the ORS Office at or before the SpaceX Flight Readiness Review, which typically occurs two weeks before launch.

The list of ORS Office Jumpstart Mission candidate payloads considered for this mission included the following:

1. Air Force Research Laboratory (AFRL) Plug and Play (PnP) satellite bus – a third generation bus with multiple integrated payloads, that when flown, would be a risk reduction to future ORS missions.
2. SpaceDev, Inc. Trailblazer spacecraft bus, originally developed under a Missile Defense Agency contract, which demonstrates a flexible, modular commercial bus design using off the shelf components.
3. Air Force Office of Scientific Research (AFOSR)/AFRL NanoSat-4, CUSat – a Space Test Program experiment consisting of two nanosatellites developed by Cornell University in partnership with the AFRL under the University Nanosatellite Program.

In addition to the ORS primary payload, the Jumpstart mission will also carry a Secondary Payload Adaptor and Separation System (SPASS) experiment for ATSB® of Malaysia who will also be the primary customer for the forth Falcon 1 launch, dubbed the F1-004 RazakSAT mission. The SPASS has the ability to carry multiple cubesats and a nanosatellite with minimum interference to the primary payload and the launch vehicle. The SPASS development and launch was funded by ATSB while the design, fabrication, test, integration and secondary satellite manifesting was handled by Space Access Technologies. For this flight, the SPASS will carry two NASA cubesats each to be deployed using Cal Poly P-POD separation system. The first secondary satellite to be deployed is called

PharmaSat Risk Evaluation Satellite (PRESat). PRESat is a NASA Ames Research Center spacecraft and is designed to host and transmit data on biological experimentation in microgravity. The second secondary satellite to be deployed comes from NASA Marshall Space Flight Center and is called NanoSail-D. The objective of NanoSail-D is to work with other NASA centers and industry to conduct a rapid low cost technology demonstration spacecraft to validate new deployable structure technology and show the utility of sails as an aerodynamic drag device.

In addition to the ORS primary payload and the SPASS with two NASA cubesats, SpaceX will also fly two Celestis payloads from Space Services Incorporated.

Jumpstart Mission Objectives

The primary ORS Office objective for the Launch vehicle team on this mission was to perform integration tasks for all three possible ORS Office payloads in addition to completing a mission (Kick off to launch) in ~4 months. In addition to responsiveness being demonstrated by the launch service provider, responsiveness was also demonstrated by the payload and ORS Office teams by building and testing each of the three payloads being considered, then testing an integrated stack. Also, each payload candidate team participated in a Jumpstart pathfinder exercise where they went to Kwajalein to plan and verify logistical operation and to set up and certify three separate ground stations for use in the mission should they be the one selected to fly.

Jumpstart Mission Operational Responsiveness

Significant breakthroughs in Operational Responsiveness were demonstrated through the integration activities of this mission. The customer kickoff meeting was held in February 2008 and the launch vehicle with the payload integrated was vertical at the pad ready for launch in June 2008 (See Figure 6, Figure 7, Figure 8, and Figure 9). Approximately four weeks prior to launch, the ORS Office made its determination on which of the three payload candidates would fly. The payload chosen was called Trailblazer and is built and operated by SpaceDev of Poway, CA. The Trailblazer spacecraft on the Jumpstart mission will serve as a flight test program to validate the hardware, software, and processes of an accelerated satellite launch. In preparation for the payload decision, the SpaceX team had demonstrated responsiveness by preparing for the possibility of flying any of the ORS payloads being considered. Specifically, documentation and analysis were completed in parallel prior to the final payload decision so that regardless of which payload was ultimately chosen, the final integration and verification activities could be completed within the final two to four weeks of the launch campaign. The multiple payload configuration analyses completed included coupled loads analysis, collision avoidance maneuver analysis, performance and trajectory analysis, and safety analysis. Three separate interface control documents were negotiated between SpaceX, the primary payload under consideration, and the Secondary Payload System teams. Additionally, the FAA demonstrated responsiveness by licensing the launch regardless of payload selected. To do this, they took the payload safety information from all three candidates and reviewed them all for acceptance prior to granting a commercial launch license enveloping them all.

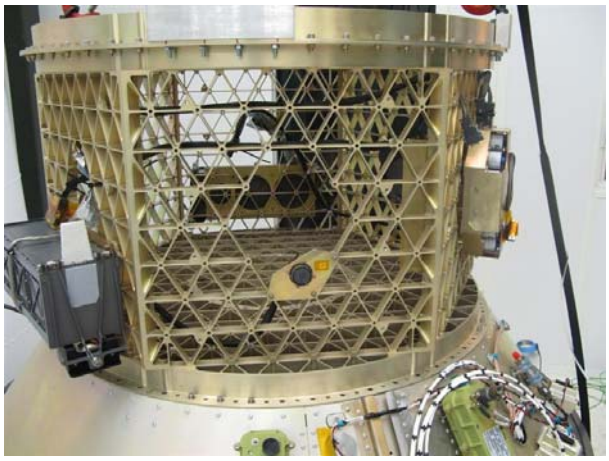

Figure 6 ***SPASS integrated onto launch vehicle payload adapter and ready for primary payload integration***

Figure 7 ***NASA Ames Research Center's PRESat being integrated into a PPOD on the SPASS***

Figure 8 ***Jumpstart mission integrated payload stack ready for fairing encapsulation***

Figure 9 ***Falcon 1 with Jumpstart mission payload integrated at Static Fire test***

It should be noted that some of the most difficult obstacles to responsiveness were not necessarily engineering related. Executing contracts and invoicing for engineering services and completed milestones proved to be somewhat non-responsive and is an area warranting considerable improvement and streamlining. Additionally, with complex missions such as Jumpstart where there are multiple parties involved, both foreign and domestic, signature cycles can be time consuming. This was especially evident when a last-minute requirement for a FAA cross-waiver arose and posed mission schedule risk. Neither of these items are showstoppers to responsiveness, but this mission has already proven useful in uncovering these issues that can now be corrected to improve overall mission responsiveness and avoid this schedule risk in the future.

CURRENT FALCON 1 MANIFEST

The launch of the Jumpstart mission is fast approaching and the Falcon 1 launch manifest (see Table 1) currently consists of three additional launches before the end of 2010. The next launch will be the RazakSAT satellite for ATSB of Malaysia which will include another handful of secondary satellites. All launches in Q2 2010 and beyond will use the upgraded Falcon 1e launch vehicle whose various upgrades were discussed herein.

Table 1 – Falcon 1 Launch Manifest

Customer	Launch	Vehicle	Launch Site
DARPA Demo 1*	Q1 2006	Falcon 1	Kwajalein
DARPA Demo 2*	Q1 2007	Falcon 1	Kwajalein
ORS (US DoD) and ATSB (Malaysia)	Q3 2008	Falcon 1	Kwajalein
ATSB (Malaysia)	Q4 2008	Falcon 1	Kwajalein
SpaceDev (US)	2009	Falcon 1	Kwajalein
SSC (Sweden)	2010	Falcon 1	Kwajalein

* completed

CONCLUSION

The Demo 2 mission represented a tremendous step forward for SpaceX and the Falcon 1 launch vehicle, and ultimately resulted in the vehicle being declared operational. The Jumpstart mission, similar to Demo 2, is showing that Responsive missions can be, and are being, executed. By going through the responsive mission integration process, many areas are highlighted where further improvements can be made to further enhance responsiveness. The Falcon 1 vehicle upgrade path will ensure that launch manifest commitments are met while continuing to improve on the baseline design, keep cost low, and reliability high.

REFERENCES

1. Falcon 1 Launch Vehicle User's Guide, Revision 7, Space Exploration Technologies, 2008, http://www.spacex.com/Falcon 1 Payload Users Guide.pdf

2. Falcon 1 Demo Flight 2 – Flight Review Update, Space Exploration Technologies, June 2007, http://www.spacex.com/F1-DemoFlight2-Flight-Review.pdf