The Falcon 1 Launch Vehicle: Demonstration Flights, Status, Manifest, and Upgrade Path

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ABSTRACT

Falcon 1, the entry vehicle in the Space Exploration Technologies (SpaceX) launch vehicle family, is designed to provide the world's lowest cost access to orbit. The vehicle is designed above all for high reliability, followed by low cost and a benign payload flight environment. It is a two-stage, liquid oxygen and rocket grade kerosene (RP-1) powered launch vehicle capable of placing a 700 kg satellite into a 200km circular orbit, inclined 9.1 degrees. Falcon 1 combines a re-usable, turbo-pump fed first stage powered by a single SpaceX Merlin engine with a pressure fed second stage powered by our Kestrel engine and capable of multiple re-starts.

A brief summary of the March 24th, 2006 maiden demonstration launch of Falcon 1 from the SpaceX Omelek Island launch facility in the Kwajalein Atoll is presented along with a detailed account of the more recent Demo 2 mission which took flight on March 21st, 2007 from the same location. Though orbit was not achieved on the Demo 2 mission, a significant majority of mission objectives were met from both programmatic and technical perspectives. Details of the eight flight anomalies experienced during the Demo 2 mission are presented herein.

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 will be implemented as a block upgrade and will increase the payload capacity to orbit over that of the current Falcon 1 configuration.

The Falcon 1 manifest is presented and includes five additional Falcon 1 launches before the end of 2009 with two taking place from Omelek Island in the Kwajalein Atoll and three from Vandenberg Air Force Base.

FALCON 1 LAUNCH VEHICLE OVERVIEW

The Falcon 1 is a two stage launch vehicle approximately 70' in height with a Gross Lift-Off Weight (GLOW) of about 61,000 lbm. The first stage for the Demonstration missions was powered by the Merlin 1A pump-fed RP-1/liquid oxygen (LOX) engine. The 2nd stage is powered by the pressure-fed Kestrel engine, also burning RP-1/LOX. This vehicle was developed entirely by SpaceX under funding provided by SpaceX founder, Mr. Elon Musk.

DEMO 1 MISSION SUMMARY

The first test flight in March 2006 suffered a fuel leak in the 1st stage engine prior to lift-off, which resulted in an engine fire and subsequent loss of thrust at T+34 seconds. DARPA and SpaceX conducted an extensive mishap and return to flight investigation and concluded that the most probable leak cause was due to intergranular cracking of an aluminum alloy B-nut. SpaceX implemented vehicle design and procedural changes to address identified flight anomalies as well as to improve system robustness and reliability. Noteworthy changes included:

- Addition of many additional autonomous sensor checks during the countdown and prior to vehicle release. These health checks can generate either warnings for the engineers or aborts depending on the condition.

- Elimination of all aluminum fittings in regions exposed to ambient environments.

- Fire protection blankets and nitrogen purges in the engine compartments.

- Additional quality control measures employed.

DEMO 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 around testing the vehicle in flight, gathering data and retiring technical risk prior to the first operational flight to launch the TacSat-1 spacecraft.

This mission, Demonstration Flight 2 or "Demo 2", was the return to flight of the Falcon 1 after significant modifications following the inaugural flight, as described above. 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 1 – The day before launch on Omelek Island

As shown in Figure 2, 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 have been identified by post-flight data analysis, thought this 2nd stage control anomaly was the only known issue that prevented this mission from achieving orbit. Vehicle performance was within an acceptable range until around T+265 seconds when an oscillation in the 2nd stage control system began to appear. This instability grew over time until about T+474 seconds when the engine shut down. Flight data indicate that propellant slosh is the most probable root cause of the control anomaly, which resulted in a vehicle roll rate sufficient to centrifuge propellant and cause flame-out of the Kestrel engine. Analysis of vehicle telemetry indicates the vehicle would have attained orbit if the 2nd stage engine had continued to burn. The vehicle attained a peak altitude of 289 km, 5.1 km/s maximum velocity and remained in the center of the intended ground track throughout flight.

Significant achievements for the Demo 2 flight include successful demonstration and verification of:

- Ground control & support systems, including control software, highly automated operations & autonomous abort
- Rapid response capability – launched after hot-fire abort
- 1st stage performance and control from lift-off through Main Engine Cut-Off (MECO)
- Vehicle structural performance & margins through lift-off, transonic & max-Q
- Stage separation
- 2nd stage ignition
- Fairing separation
- 2nd stage engine performance in vacuum
- Guidance, navigation & control performance through T+~300s, including transonic
- Flight software through all major flight domains
- Launch & flight environments: thermal, shock & vibration
- Aero-thermal and base-heating (both stages) results

Operational Responsiveness

Significant breakthroughs in Operational Responsiveness were also demonstrated by this mission. The entire mission timeline, from Customer Kick-off to launch, was achieved in 8 months and one week (this included significant vehicle design changes, re-qualification of vehicle avionics, refurbishment of the launch site and integration of a complex payload). The vehicle integration process was non-contiguous due to several interruptions due to technical issues associated with the developmental status of the Falcon 1. However when the initial integration timeline from arrival up to Flight Readiness Review (FRR) is combined with the final launch campaign (Roll-out onward), the resulting total campaign duration is only 39 days from arrival at the launch site to launch. This assumes only 10 hour work days and could be shortened significantly by employing 24/7 work crews. Furthermore, this 39 day campaign included a full Static Fire, associated data analysis and re-configuration for launch. When Static Fire and associated activities are removed from the actual campaign timeline, this mission came close to achieving the original DARPA Falcon Program objective for "Call-up" (Storage to Alert Status) of <24hrs (assuming a 24/7 work force), and did easily achieve the objective for Alert Status to Launch of <24hrs. The values derived from the actual timeline are 47hrs and 6hrs respectively and are projected to fall to 35hrs and 4hrs respectively in an operational system.

This mission also demonstrated a highly autonomous ground control system and rapid recycle from a hot-fire abort to launch in under 70 minutes. On launch day, the first countdown was autonomously aborted by control software at T-0.5 seconds, when it detected that engine chamber pressure was ~0.2% under the designated threshold. After a partial de-tank and re-tank to warm the fuel, the vehicle was launched on the second attempt. This successful rapid turn-around would not have been possible without the autonomous ground control software and auto-sequences developed for the Falcon 1.

Mission Objectives

Figure 2 shows mission technical objectives for the vehicle and ground systems, broken down by subsystem. Overall, 86% of technical objective are considered to be fully achieved by this mission and associated risks retired. An additional 5% were partially demonstrated. Programmatically, 24 mission objectives were explicitly listed in the contract, including some high-level technical objectives. 17 of these were fully achieved, plus another 5 were partially demonstrated. In each case, those objectives that were not demonstrated, or only partially so, were in phases of flight not reached before shut-down.

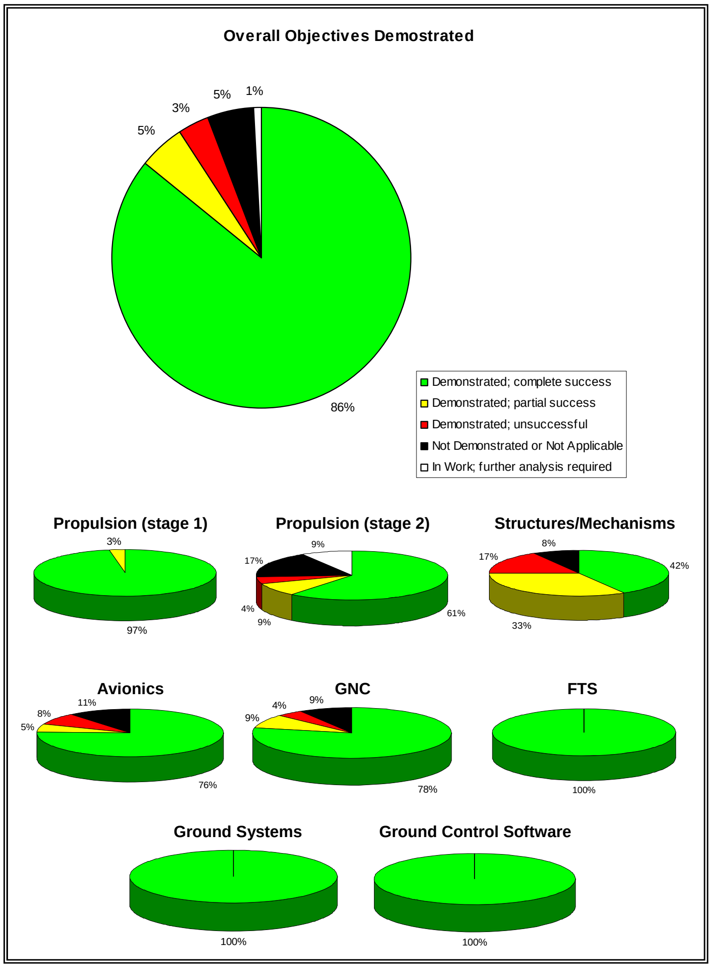


Figure 2 - Demo 2 Technical Objectives

Payload

A payload was accommodated on this flight as a secondary objective at the request of DARPA/AF. Part of this payload was the Autonomous Flight Safety System (AFSS) and the Low Cost TDRSS Transmitter (LCT2), plus associated hardware, battery and antennas. AFSS is a rule-based autonomous flight termination system (FTS), which operated in shadow mode for this mission and was not connected to the vehicle FTS. AFSS and LCT2 are a NASA-developed launch vehicle payload aimed at reducing range communications & tracking costs including flight termination system support from the ground during flight. On this flight the LCT2 was configured to transmit AFSS data back to the Mission Control Center, closing a link through a TDRSS spacecraft during terminal count on the launch pad and continuing to transmit through orbit insertion.

Due to SpaceX concerns about a possible Radio Frequency Interference (RFI) issue between vehicle systems and LCT2, based on three suspicious events in the days before launch, the decision was made by SpaceX, with DARPA's concurrence, to fly with LCT2 powered down. Consequently LCT2 was not demonstrated during flight. Some AFSS data, however, were also embedded in the vehicle telemetry stream, allowing them to exceed minimum success criteria even without LCT2. An investigation of this RFI issue was performed post-flight and did identify the potential for subtle and intermittent interaction between these systems though the observed effects could not be reproduced under flight-like conditions. This interaction appears to be due to a susceptibility of the vehicle GPS receiver and not to the LCT2 transmitter itself.

Anomalies

There were eight significant Anomalies identified during analysis of flight data, including the 2nd stage control issue. Addressing and correcting these items constitute a constraint on the next flight of the Falcon 1 vehicle. These anomalies are summarized below.

1. 2nd Stage LOX Quick Disconnect (QD) failed to disconnect during lift-off

This resulted in the LOX QD panel (with QD) and ~2" of LOX fill line separating from vehicle. An internal LOX check-value prevented any loss of propellant from the vehicle and there is no evidence of other damage to the stage nor that this contributed in any way to other flight anomalies or observations. SpaceX is planning to either work with the QD vendor to correct this issue or develop a "Hybrid" QD panel in house using supplier (Wiggins) part(s).

2. 1st Stage LOX, Fuel and Electrical QD's failed to disconnect per design at lift-off

The LOX and fuel QDs each traveled several inches further with the vehicle than intended before separating nominally at the connectors. The Electrical QD lanyard broke and pulled the umbilical approximately 18" before separating at the ground-side connector back-shell. Apart from a roll correction maneuver as the vehicle lifted off the pad, there is no indication these contributed in any way to other flight anomalies or observations. SpaceX is investigating whether QD panel installation may have been a potential contributor and is also re-evaluating the design of QD panels and considering implementing a secondary QD separation mechanism.

3. 1st Stage Trajectory Performance

Two parts to this anomaly:

a. An outdated Propellant Utilization (PU) file set was loaded into the Engine Computer. The PU function is initiated at T+20s and governs the limits of the Fuel Trim Valve and therefore the engine mixture ratio. This error resulted in an incorrect setting for the Fuel Trim Valve high limit. The impact on the flight was an altered thrust profile. Thrust was lower than intended early in the flight resulting in increased gravity losses and causing the first stage trajectory to be slightly lower and slower than predicted. The vehicle could still have achieved the intended orbit however, if not for Anomaly 7 below (2nd stage control anomaly). This anomaly is fundamentally a configuration control issue since this configuration file was not verified prior to launch. SpaceX is revising the pre-launch sign-off process to ensure all configuration files are reviewed and signed-off prior to loading.

b. The 1st stage LOX tank ullage pressure dropped near end of the burn causing the LOX pump to cavitate (chug) and inducing Pogo. This is attributed to low helium margin and helium temperature. This issue is being addressed by revisiting tank pressure set-points and pressure control dead-bands.

4. 2nd Stage Propellant Utilization (PU) did not control tank pressure to regulate engine mixture ratio

The second stage PU function does not appear to have operated correctly during the 2nd stage engine burn. This anomaly is still under active investigation and may be a secondary effect of other anomalies. If Anomaly 7 below (2nd stage control anomaly) had not occurred, this anomaly would have resulted in higher residual propellant at the end of 2nd stage burn, decreasing the vehicle's performance and mass margin by an unknown amount.

5. Re-contact during stage separation

The nozzle of the Kestrel engine made contact with the interstage section as they separated after MECO. This occurred due to higher than anticipated rotation rates, both of the combined vehicle stack prior to separation, and of the 2nd stage after separation but before clearing the interstage section. This rotation occurred during unpowered flight between MECO and 2nd stage ignition. The Merlin 1st stage engine was pointing slightly off center-of-mass at shutdown and off-axis forces due to thrust tail-off and engine purge account for some of these rotational torques on the stack. The remainder of this rotation is currently attributed to aero-loading of both the combined stack and the 2nd stage after separation, due to being 15 km lower than expected during stage separation. This anomaly is therefore directly attributable to Anomaly 3 above.

6. *One of two Marmon clamp joints failed to separate at fairing jettison*

The Marmon band that clamps the bottom of the payload fairing until jettison is retained by two redundant pyro-bolts. Video observation shows that the two halves of this band are apparently still joined as it falls away from the vehicle. The other bolt did fire and the fairing halves separated nominally. This anomaly is still under investigation. All pre-flight test data appears nominal. Vehicle telemetry is not be of sufficient time resolution to deduce whether both pyros actually drew current.

7. *Loss of Control of 2nd Stage*

An oscillation appeared in the 2nd stage control system approximately 90 seconds into the burn. This instability grew in pitch and yaw axes initially, then after about 30 seconds induced a roll also. This roll eventually built up to a rate sufficient to centrifuge the liquid propellants and causing flame-out of the Kestrel engine. Although multiple potential causes are still under investigation, there is high confidence that LOX slosh was the primary contributor to this instability. This vehicle did not use slosh baffles in the second stage tanks. They are now being designed for inclusion in future flights, along with other possibly complementary mitigations, including potential adjustments to guidance rules. Observed excessive 2nd stage helium usage is a secondary effect of this anomaly due to ullage chilling by LOX movement inside the tank.

8. *1st Stage Location and Recover*

The 1st stage was not recovered as planned. The recovery vessel received no signals from the electronic, sonar or visible location aids. The Range tracked the stage and received telemetry after MECO until it dropped below the horizon, but it was still at ~50 km altitude at that time. The parachute nominally deploys at 4 km altitude. Consequently there are no data to verify parachute system deployment. There were also significant delays reaching predicted splash-down point due to inaccurate landing location assessments from the Range which were initially approximately 20nm off. A long stand-off distance was required for the recovery vessel which resulted in travel time to the splash-down site of 4~5 hours. SpaceX is planning to add redundancy to the GPS locator system and increased thermal protection to the stage. It should be noted that recovery of this stage was a SpaceX-internal goal only and not a customer requirement.

Vehicle Performance Assessment

Prior to the upper stage control anomaly, vehicle retained ample margin to reach orbit. Even with this anomaly, if the instability had not resulted in a roll, vehicle still retained enough margin to reach orbit. Due to performance-optimizing saturation in guidance algorithm, vehicle would have been 6 km low at perigee (i.e. 324 x 685 km) at orbital insertion, which is well-within stated insertion accuracy on ±10 km.

Translating this performance to the industry-standard circular reference orbits, this specific vehicle could have inserted masses shown in Table 1 into orbit.

Table 1 - Extrapolated Vehicle Performance

From:	To: Inclination	To: Altitude	With S1 PU Anomaly	Without S1 PU Anomaly
Kwajalein	9°	200 km	582 lbm	666 lbm
Cape Canaveral	28.5°	185 km (100 nmi)	551 lbm	635 lbm

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.

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.

Stage 1 recovery not demonstrated and represents the only operational domain from which data were not attained by this mission. Additionally stage 2 coast and Kestrel re-start was not demonstrated, nor was Payload simulator deployment. The LCT2 TDRSS transmitter was flown un-powered; AFSS/LCT2 will be flown on a future SpaceX mission. Eight anomalies were identified which are constraints to next mission. Twenty-four observations to date will most likely require further action (changes to procedures, processes, limits, config files, LCCs, Op notes etc.).

The many successes of this mission and the large amount of flight data obtained, including on anomalous behaviors, have greatly reduced risks for the next Falcon 1 mission to launch the TacSat-1 spacecraft.

FALCON 1 STATUS

Overview

Due to the successes of the Demo 2 mission in retiring risks in the ground and flight systems, SpaceX has declared the Falcon 1 ready to exit the demonstration program and has upgraded the launch vehicle to operational status. That being said, there are still a set of changes that must be made to the vehicle in support of near term missions to be executed through 2008. These vehicle changes are called interim upgrades as they will only be used for a short while before the larger block upgrade comes to fruition in 2009. The interim upgrades described here result in an additional 362 lbm (164 kg) of payload capacity which is needed to support the upcoming operational payloads requirements.

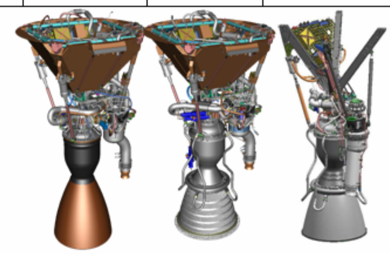
Interim Upgrades

1. Stage 1 Engine Upgrade

An upgraded version of the already qualified Merlin engine will be used on future missions through 2009. This engine is intended to increase reliability, increase Specific Impulse (I_{sp}) by 5-7%, and increase thrust by ~7%. Major changes include upgrading the combustion chamber from ablatively cooled to regeneratively cooled, and changing from torch ignition to a pyrophoric system using TEA-TEB (similar to what is currently used on the second stage). This new engine will be called Merlin 1C-F1 or M1CF1 and its characteristics, as compared with the previously flown M1A version as well as the future upgrade called M1C or M1C-F9, are shown in Table 2.

Table 2: Merlin Engine upgrade path

Parameter	Merlin 1A (Demo Flights)	Merlin 1C-F1 (Interim upgrade)	Merlin 1C-F9 (Falcon 1e and future)
Sea Level Thrust (lbf)	73,000	78,400	92,000
Vacuum Thrust (lbf)	83,000	88,700	105,500
Mixture Ratio (O/F)	2.20	2.20	2.20
Chamber Pressure (psia)	782	825	959
Nozzle Expansion Ratio	14.5	14.5	14.5
Isp Sea Level (sec)	244	256	263
Isp Vacuum (sec)	288.5	302.5	302
Engine Length (ft)	9.5	9.6	9.4
Engine Diameter (ft)	5.5	5.5	4.7



2. Stage 2 Engine Upgrade

The Stage 2 Kestrel engine is undergoing weight savings and reliability enhancements. Changes include a lighter weight and more easily manufactured thrust frame, a lighter weight ablative chamber, and the LOX and Fuel main valves and burst disks are being redesigned for added reliability. The new engine will be called Kestrel 2 or K2.

3. Stage 2 Tank Upgrade

As a weight savings measure, the stage 2 tank material has been changed from aluminum 2219 to a 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 loss of control anomaly experienced during the Demo Flight 2 mission. An illustration of the slosh baffle addition is shown in Figure 3.

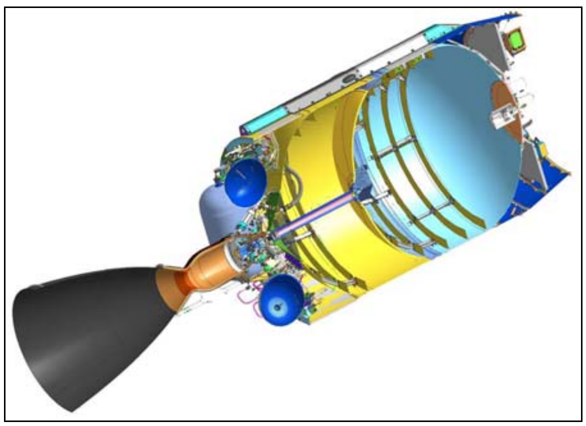


Figure 3 – 2nd Stage baffle upgrade

FALCON 1 FUTURE BLOCK UPGRADES

Overview

Consistent with SpaceX's corporate philosophy of rapid and continuous improvement, Falcon 1 has a planned upgrade path based upon experience from the first missions and our design work on its sister vehicle, the Falcon 9. Similar to the interim upgrades, the block enhancements to the Falcon 1, making it a Falcon 1e or F1e, are all designed to deliver increased payload capacity along with increase reliability. The future block upgrades described here will include an upgrade to the 1st stage tank primary structure to support the thrust and propellant needs of a full Merlin 1C engine. This will be the same engine used on the Falcon 9 launch vehicle and has both performance enhancement as well as reliability enhancements built into it. In addition, the second stage tank material will be revised again for mass savings and a larger fairing will be offered. These enhancements improve payload capacity and volume substantially versus the initial vehicle. A Falcon 1 upgrade path map is shown in

Table 3.

Future Upgrades

1. Stage 1 Engine Upgrade

As depicted in Table 2, the F1e will employ a Merlin 1C (M1C) engine which will be the same engine used for Falcon 9 missions. The engine will deliver 105,500 lbf Thrust (VAC) with ISP in the 302-304s range. Upgrades to this engine above and beyond the M1C-F1 include a thrust frame redesign that reduces cost and manufacturing time, an upgraded turbo pump assembly, upgraded avionics, and open cell isogrid panels to mitigate acoustic coupling into the thrust structure where avionics and other components are mounted.

2. Stage 1 Tank Upgrade

The higher thrust of the M1C engine being used on the F1e would exceed the the qualification margins of the existing 1st stage tanks. These tanks would also not be large enough to support the additional propellant needs of the larger engine. Therefore, the 1st stage tank structure will be redesigned, built and qualified to meet the propellant needs and load requirements of the M1C engine. This change will stretch the 1st stage tank and therefore increase the Falcon 1 launch vehicle length from ~70' (F1) to ~85' (F1e) in overall height.

Table 3 – Falcon 1 Upgrade Path

	Demos 1 & 2		2007-2008 (TacSat-1, RazakSat)		2009 onwards (F1e)	
Characteristic	**Stage 1**	**Stage 2**	**Stage 1 (2007-2009)**	**Stage 2**	**Stage 1 (2009+)**	**Stage 2**
Vehicle Diameter	5.5 ft (1.7 m)	Stage 5.5 ft (1.7 m)	5.5 ft (1.7 m)	Stage 5.5 ft (1.7 m)	5.5 ft (1.7 m)	Stage 5.5 ft (1.7 m)
Stage Material	2219 Aluminum	2219 Aluminum	2219 Aluminum	**2014 Aluminum**	2219 Aluminum	**2195 Aluminum-Lithium**
Fairing Diameter	-	5 ft (1.5 m)	-	5 ft (1.5 m)	-	**5.5 ft (1.7 m)**
Number of Engines	1 Merlin 1A (ablative)	1 Kestrel	**1 Merlin 1C (regen.)**	**1 Kestrel 2**	**1 Merlin 1C (regen.)**	**1 Kestrel 2**
Engine Type	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene
Propellant Feed System	Turbo-pump	Pressure-fed	Turbo-pump	Pressure-fed	Turbo Pump	Pressure-fed
Thrust (vac)	72k lbf (32,660 kg f)	7k lbf (3,175 kg f)	**92k lbf (41,730 kg f)**	7k lbf (3,175 kg f)	**115k lbf (52,160 kg f)**	7k lbf (3,175 kg f)
ISP (sea level / vac)	245 s / 290s	315 s	**255 s / 304 s**	**330 s**	**255 s / 304 s**	**330 s**
Tank Pressurization	Heated Helium	Heated Helium	Heated Helium	Heated Helium	Heated helium	Heated Helium
Restart Capability	No	Yes	No	Yes	No	Yes
Attitude Control: Pitch/Yaw	Hydraulic TVC	Elect-mech. TVC Actuators	Hydraulic TVC	Elect-mech. TVC Actuators	Hydraulic TVC	Elect-mech. TVC Actuators
Attitude Control: Roll	Turbo-pump exhaust	Cold gas thrusters	Turbo-pump exhaust	Cold gas thrusters	Turbo-pump exhaust	Cold gas thrusters
Nominal Burn Time	169 s	418 s	169 s	418 s	169 s	418 s
Shutdown Process	Burn to depletion	Predetermined Velocity	Burn to depletion	Predetermined Velocity	Burn to depletion	Predetermined Velocity
Payload Capacity (KSC, 200km, 28.5°)	630 lbm (285 kg)		**992 lbm (450 kg)**		**1543 lbm (700 kg)**	

3. Fairing Upgrade

The added performance of the M1C engine provides for additional payload capacity which can be in the form of a heavier or a larger spacecraft. To accommodate the latter, SpaceX is planning to upgrade the current fairing design with a volumetrically larger fairing. The current design is a bi-conic aluminum skin and stringer design with a diameter of 1.5m (60in). The F1e variant will be a composite ogive shape with a 1.7m (67in) diameter. A comparison of the current and planned fairing designs is illustrated in Figure 4.

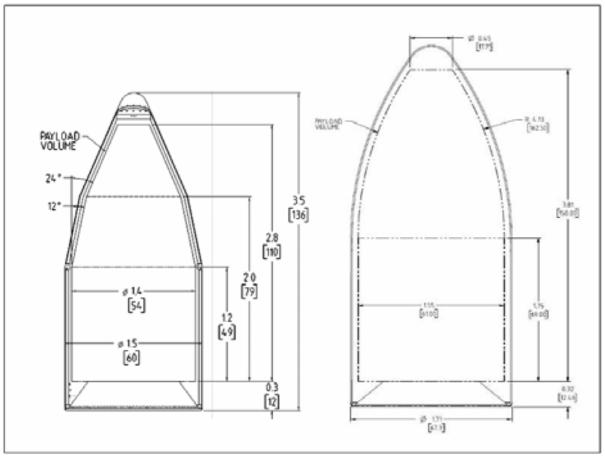


Figure 4 – Falcon 1 and Falcon 1e payload fairing dimension comparison

4. Stage 2 Tank Upgrade

Further mass savings will be achieved on the second stage tank by changing the tank material from the interim aluminum 2014 alloy to an aluminum-lithium 2195 alloy similar to that used on the Space Shuttle external tank. Slosh baffles will remain to prevent further occurrences of the Demo 2 stage 2 control issue.

CURRENT FALCON 1 MANIFEST

The Falcon 1 launch manifest (see Table 4) currently consists of five additional launches before the end of 2009. The next launch will be the first operational launch of Falcon 1 carrying a US Government Satellite, TacSAT-1, which will then be followed by the launch of satellite for ATSB of Malaysia which will include a handful of secondary satellites. Both of these launches will be on the standard Falcon 1 with the interim upgrades and are to be launched from Omelek Island in the Kwajalein Atoll. The launches in 2009 and beyond will use the upgraded Falcon 1e launch vehicle. In 2009, SpaceX plans to pick up launches from its second operational launch facility at Vandenberg Air Force Base where SpaceX currently occupies Space Launch Complex-3 West (SLC-3W).

Table 4 – Falcon 1 Launch Manifest

Customer	Launch	Vehicle	Launch site
Falcon Demo Launch 1*	Q1 2006	Falcon 1	Kwajalein
Falcon Demo Launch 2*	Q1 2007	Falcon 1	Kwajalein
OSD/NRL	Q4 2007	Falcon 1	Kwajalein
ATSB/Malaysia	Q1 2008	Falcon 1	Kwajalein
SpaceDev	Q1 2009	Falcon 1e	Vandenberg AFB
Swedish Space Corp	Q4 2009	Falcon 1e	Vandenberg AFB
(Proprietary)	Q1 2010	Falcon 1e	Vandenberg AFB

* completed

CONCLUSION

The Demo 2 mission represented a tremendous step forward for SpaceX and the Falcon 1 launch vehicle. The Falcon 1 launch vehicle is ready to exit the demonstration mode and be declared operational status. The vehicle upgrade path discussed herein will ensure that launch manifest commitments are met while continuing to improve on the baseline design, keep cost low, and reliability high.

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