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

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Falcon 1 Introduction



- Payload capability: Over 1500 lbs to LEO (28.5 deg, 200 nm, circular)
- Launch from Vandenberg AFB, and Kwajalein (Reagan Test Site)
- Multiple manifest, multiple orbit
- \$7.0M per launch for single flight contracts. Price includes Range fees.
 - Block upgrade planned to create <u>Enhanced Falcon 1 (F1e)</u> cost will be \$8.5M with availability planned in 2009.
- General Falcon 1 data:
 - Length 68'
 - Diameter 5.5' tapering to 5'
 - 1st Stage LOX/RP1 engine
 - 2nd Stage LOX/RP1 engine
 - 38" diameter payload attach fitting
 - 1.5m diameter fairing
 - 1st Stage Parachute to Water Recovery
 - Additional specifications can be found in the Payload Users Guide at <u>www.spacex.com</u> s



Space Exploration Technologies Corporation Spacex.com

Demo Flight 1 Overview

- 1st test flight of the Falcon 1 launched on March 25, 2006
- From: RTS, Omelek, Kwajalein Atoll
- Customer: DARPA/USAF

Objectives:

- Operationally Responsive Launch
- Retire risk prior to operational flights
- Collect flight data on the vehicle
- Validate ground systems
- Orbit: 39°, 400 x 500 km
- Payload: FalconSAT-2 (USAFA)







Photo Credit: Thom Rogers/SpaceX

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Demo Flight 1 Summary



- Fuel leak in the 1st stage engine prior to lift-off caused an engine fire and subsequent loss of thrust at T+34 seconds
- DARPA and SpaceX 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, including:
 - Additional autonomous sensor checks during the countdown and prior to vehicle release
 - Elimination of all aluminum fittings in regions exposed to corrosive environments
 - Fire protection blankets and nitrogen purges in the engine compartments
 - Additional quality control measures employed



Demo Flight 2 Overview



2nd test flight of the Falcon 1 launched March 21, 2007

- From: RTS, Omelek, Kwajalein Atoll
- Customer: DARPA/USAF

Objectives:

- Operationally Responsive Launch
- Retire risk prior to 1st operational flight
- Collect flight data on the vehicle
- Validate ground systems
- Parking Orbit: 9°, 330 x 635 km
 Final Orbit: 9°, 635 km circular
- Payload (secondary objective):
 - AFSS/LCT2 for NASA WFF
 - 38.81" LightBand (empty)

Demo 2 Launch Video



SpaceX Falcon 1-001 Launch Demo 2 Mission, March 21, 2007 Kwajalein Atoll, Omelek Island Reagan Test Site

Demo Flight 2 Results



Falcon 1 reached space! (...but it didn't stay there); 289km altitude; 5.1 km/s

- Major flight events were successfully demonstrated except Payload Separation & Restart
- Majority of Mission Objectives (programmatic & technical) were achieved
- Validated:
 - Ground control & support systems, including autonomous control & ops software
 - 1st stage performance and control from lift-off through Main Engine Cut-Off
 - Vehicle structural & GN&C incl. margins through lift-off, transonic & max-Q
 - Stage & fairing separation
 - 2nd stage ignition & engine performance in vacuum
 - Flight software through most major flight domains
 - Launch & flight environments
 - Reduced pad acoustic environments

• Operational Responsive Space launch demonstrated:

- 239 days = total mission duration (KO to Launch)
- 108 days = executed complex payload integration
- 39 days = campaign duration (non-contiguous)
- 47 hrs = work-hours from "storage" to launch
- 6 hrs = from "Alert" to launch
- 65 min = fastest hot-fire recycle ever demonstrated





One issue prevented us from getting to orbit

- 2nd stage control issue: slosh
 - Flight data points to an unstable slosh/control system interaction
 - Oscillations began in pitch/yaw axes @ T+265s
 - Coupled into roll axis; exceeded roll control authority @ T+295s
 - Roll rate caused centrifuging of propellants & flame-out @ T+474s
- Additional observations:
 - If we had not centrifuged (i.e. Kestrel continued to burn) we would have achieved orbit within spec. (perigee ~6 km low)
 - Vehicle ground track stayed in center of corridor throughout flight
 - Vehicle IIP stayed <4.5 km from nominal throughout the mission. (i.e. GNC worked well under strenuous conditions)

This is precisely the type of issue that is difficult to verify prior to flying

Demo Flight 2 Results: Anomalies

- 1st stage was "low & slow" due to software configuration file error
 - Affected thrust profile \rightarrow 15km low at MECO \rightarrow contributed to re-contact during separation

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- Result: incorporated a more rigorous buy off of configuration files
- Quick-Disconnect anomalies
 - 2nd Stage LOX QD failed to disconnect
 - Result: redesign of the Q/D
 - 1st stage LOX, fuel & electrical QDs various degrees of significance
 - Result: continue to focus on separation events & systems
- Video shows 1 of 2 redundant fairing clamp bolts didn't separate (fairing separated nominally)
 - Result: Additional wire/connector shielding being employed as a preventive measure
- Second stage propellant utilization failed to activate
 - Result: More rigorous software testing and implementation of additional software flags to make future debugging easier
- RF Interference issue resulting in LCT2 being powered down before flight
 - Result: detailed characterization of the vehicle radiated and conducted susceptibility & emissions to be performed

None of these had any direct impact on reaching orbit

Falcon 1 Status



- Falcon 1 launch vehicle changes in work to address both ground processing and in-flight anomalies experienced during the Demo Flight 2 launch campaign
 - New stage 2 baffle design
 - Quick Disconnect redesign and qualification
 - Electromagnetic compatibility testing underway
- In addition, planned launch vehicle upgrades are in work
 - 1st and 2nd stage engine performance/reliability improvements
 - Both engine designs are now finishing development and entering qualification
 - Second stage tank material changed to a lighter weight aluminum alloy
- Vehicle Production on track for hardware delivery on island in the December 2007 timeframe
- Second Falcon 1 vehicle being produced in parallel

Falcon 1 Manifest

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<u>Customer</u>	<u>Launch</u>	<u>Vehicle</u>	<u>Departure</u> <u>Point</u>
OSD/NRL Tacsat-1	Q1 2008	Falcon 1	Kwajalein
Malaysia RazakSAT™	Q1 2008	Falcon 1	Kwajalein
SpaceDev	Q3 2009	Falcon 1	VAFB
MDA Corp	Q1 2010	Falcon 1	VAFB
Swedish Space Corp	Q1 2010	Falcon 1	VAFB

Also in process of on-ramping to NASA Launch Services



Falcon 1 Upgrade Path

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Demo flights

- Merlin 1A ablative engine
- 2219 Aluminum upperstage
- Kestrel-1 upperstage engine
- Skin/stringer fairing
- ~700 pounds to orbit
- Next 3 flights
 - De-tuned Merlin 1C (M1) Regen engine
 - 2014 aluminum upperstage
 - Kestrel-2 upperstage engine
 - Slosh baffles
 - Skin/stringer fairing
 - ~1200 pounds to orbit

Late 2009—Falcon 1e

- Full Merlin 1C (M9) performance
- Longer first stage
- 2198 Aluminum upperstage
- Composite ogive fairing
- ~1800 pounds to orbit



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Merlin Engine Upgrade – M1A to M9

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Parameter	Merlin 1A	M1 (M1C-F1)	M9 (M1C-F9)
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

SpaceX Merlin Engine commonality:

- RP1/LOX
- Pintle Injector Geometry
- Pump-fed Gas Generator Cycle
- Turbine Exhaust Roll Control
- Hydraulic TVC
- Possible best-in-class performance



Kestrel Engine Upgrade K1->K2

- Changes made to increase reliability, reduce mass, and increase manufacturability
 - Changes include:
 - New LOX and RP1 main valve design
 - New dome design
 - Thrust structure changed from Titanium to Aluminum
 - Lightweight thrust chamber
 - Mass savings = 25 + 1bs





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Falcon 1 Performance Upgrade



Payload Performance from Kwajalein, Two Burns (Falcon I and Falcon Ie)



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Falcon 1 Fairing Upgrade



- Current F1: Bi-conic aluminum skin & stringer
 - 1.5m diameter
- Future F1e: Composite ogive
 - 1.7m diameter planned
 - Current design is in trade, with final design work planned for Q1 2008
 - Looking for Small Satellite community design input



Current F1 fairing

Notional F1e fairing





- SpaceX has matured as a launch service provider
- Tremendous progress towards getting to orbit
- Operations continue to be more and more responsive
- Vehicle upgrades are in work to better serve the needs of the small satellite market
- Looking forward to returning next year with 2 success stories to share