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THE FALCON I LAUNCH VEHICLE

Making Access to Space More Affordable, Reliable and Pleasant

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Abstract: Falcon I is the first in a family of launch vehicles designed by Space Exploration Technologies to facilitate low cost access to space. Falcon I is a mostly reusable, two stage, liquid oxygen and kerosene powered launch vehicle. The vehicle is designed above all for high reliability, followed by low cost and a benign flight environment. Launched from Vandenberg, a standard Falcon I can carry over 1000 lbs to sun-synchronous orbit and 1500 lbs due east to 100 NM. To minimize failure modes, the vehicle has the minimum pragmatically possible number of engines (two) and stage separation events (one), as well as dual redundant avionics. Since the first stage is recovered via parachute to a water landing, approximately 80% of the vehicle mass is reusable as compared with 90% for the Space Shuttle. The costs, which nominally assume no advantage for recovery, are $5.9M for a standard Falcon I. First launch is scheduled for fall 2004 from Vandenberg, carrying a US government satellite.

Falcon Family

The Falcon I launch vehicle is a member of the Light Lift class of launch vehicles. The vehicle is propelled by liquid propellants, liquid oxygen and kerosene, and currently no solid motors are used in the system. Our next vehicle in the family, Falcon V (Figure 2), is a medium lift class launch vehicle capable of lifting up to 10,000 lbs to low Earth orbit, depending on the altitude and inclination. This vehicle is very similar to the Falcon I, only larger. Falcon V has two stages, both propelled by liquid propellants (again liquid oxygen and kerosene). The first stage has five Merlin engines, the same engine that powers the Falcon I first stage. The second stage will be available in a number of variations, depending on the mission and capability desired.

The Falcon V brings the family's reliability to new levels with the first American rocket with true engine-out reliability in three decades. Depending upon the phase of flight, Falcon V will be capable of losing any three of the five engines and still complete its mission. Historically, engine related problems are the overwhelming cause of launch vehicle failures. The first launch of the Falcon V vehicle is expected in fall 2005. Falcon V is priced at $12M.

Figure 1: Falcon 1

Falcon I Overview

The Falcon I diameter is 1.67 m (66"), tapering to 1.5 m (60") at the fairing, and length is about 21 m (70 feet). Usable internal fairing diameter is 1.4 m (4.5 ft) (Figure 1). The first stage uses a turbopump to feed the propellant, while the second stage uses a pressure fed system.

The first stage has a LOX/kerosene engine with 72 Klb (320 KN) thrust at sea level, increasing to 84 Klb (377 KN) at vacuum. The engine propellant is pressurized by a turbopump, which is driven by a gas generator. A helium system is used to pressurize both propellant tanks during flight. The turbopump and gas generator are stage-mounted, and the first stage main engine is gimbaled by hydraulic actuators using the high pressure kerosene from the turbopump high pressure outlet. The "used" kerosene is recycled into the main fuel tank. The gas generator outlet, which produces between 350 and

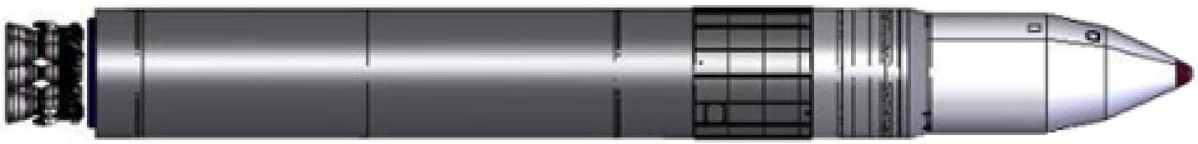

Figure 2: Falcon V

500 lb thrust, is gimbaled to produce roll control for the vehicle.

An engine computer controls the engine startup and aborts if the gas generator, turbopump or main engine show anomalous parameters. The engine computer also drives and controls the two servo valves of the gimbal system and collects some of the telemetry in the engine bay. The engine computer is connected to the flight computer in the second stage avionics bay with an Ethernet LAN.

The thrust frame (Figure 3) carries the thrust into the skirt and the fuel tank. The fuel and LOX tank share a common bulkhead, and the LOX propellant line is an integral part of the fuel tank, similar to the Saturn-V design. The fuel tank, made of Al 2219, has a volume of 2200 gallons; the LOX tank has a volume of 3400 gallons and is also made of Al 2219. The interstage is mounted on top of the LOX tank and accommodates a parachute for the recovery and the engine of the second stage. The second stage flies out of the interstage, pushed by pneumatic cylinders. The parachute of the first stage fits inside the second stage engine and is thermally protected against the second stage plume.

The second stage (Figure 4) is pressure fed, using helium as pressure gas. The engine has 7500 lb thrust and an expansion ration of 60:1. This engine is gimbaled by electrical actuators. Both propellant tanks are made of an aluminum-lithium alloy; the helium high-pressure tanks are composite over-wrapped tanks. Like the first stage tanks, the second stage tanks share a common bulkhead with the LOX tank forward of the fuel tank. The pressurant bottles are accommodated below the tanks, while the avionics bay is located on top of the tanks, under the payload adapter.

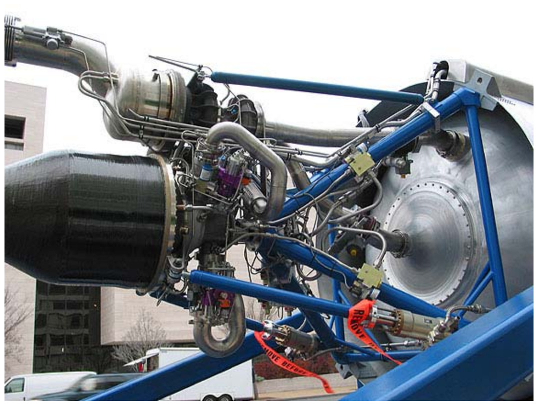

Figure 3: First Stage Engine

The avionics components include the redundant flight computer and IMU, which is a fiber-optical gyro/accelerometer unit. A GPS receiver provides position and velocity and allows compensating for wind drift. The flight computer is a PC/104 based Intel-486 computer with analog and digital input and output. The flight computer is to a large extent identical to the engine computer. The avionics system includes an S-band telemetry system, a video downlink, a C-Band transponder and other

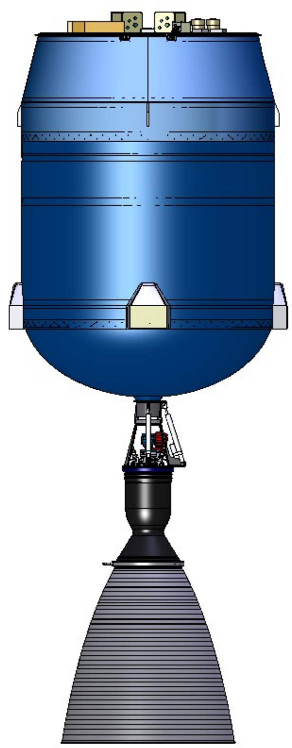

Figure 4: Falcon 1 Second stage

components. The flight computer provides an interface to the payload via Ethernet (Figure 5). The flight termination system is a thrust termination system, relatively unique for launch vehicle systems.

vehicle. Depending on the desired orbit and the payload, either a direct insertion or an orbital insertion into a lower, eccentric orbit with a second burn at apogee may be selected (a two impulse burn), see Figure 7 and 8. The azimuth limitation (Figure 9)

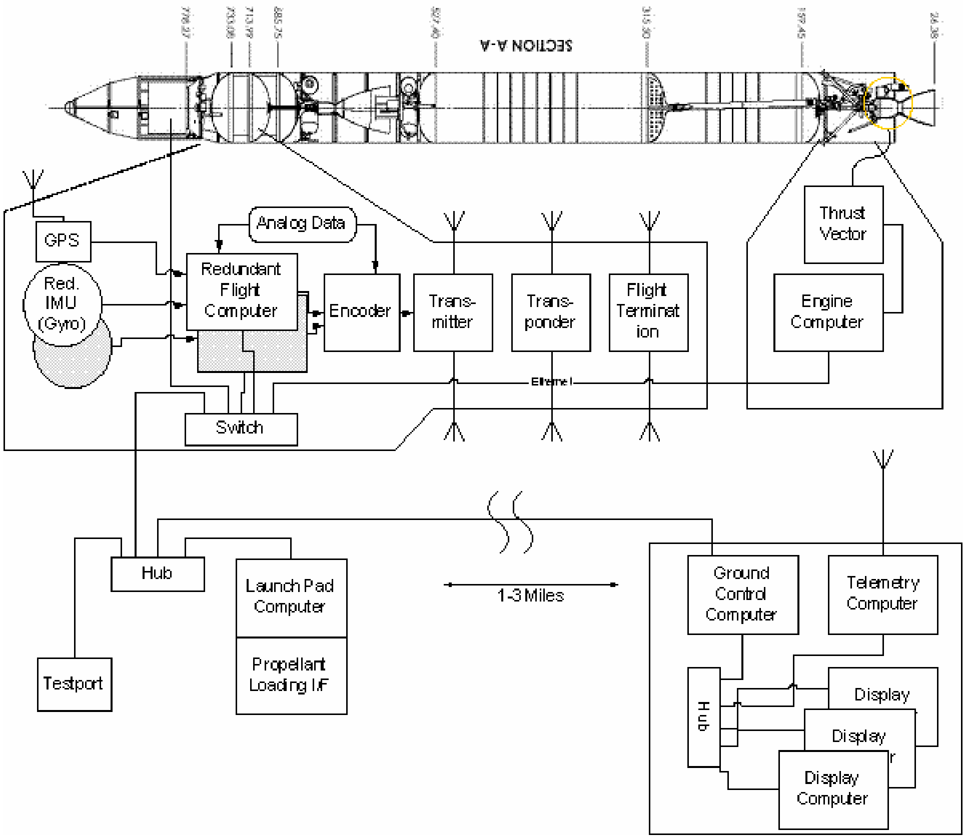

Figure 5: Avionics Architecture

Trajectory and Performance

Three launch locations (Vandenberg Air Force Base, Cape Canaveral Air Force Station, and an equatorial site) and a liquid propulsion system with re-start capability provide all the flexibility and performance required from a modern launch system. Figure 6 shows a typical trajectory from Vandenberg, where SLC-3W is currently being modified for the Falcon I vehicle. prevents the vehicle from flying to close to populated areas; a dogleg maneuver is therefore required to achieve these lower inclinations. The azimuth limitation depends on the payload and the demonstrated vehicle safety. During the ascent, the maximum acceleration reaches approximately 6 g's. Falcon V performance is also shown in Figure 10.

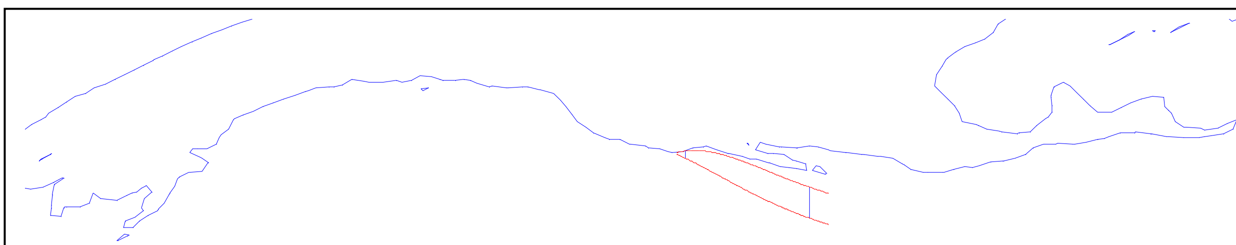

Figure 6: Trajectory for a Typical Launch from Vandenberg. Vertical lines mark the first and second engine burnout.

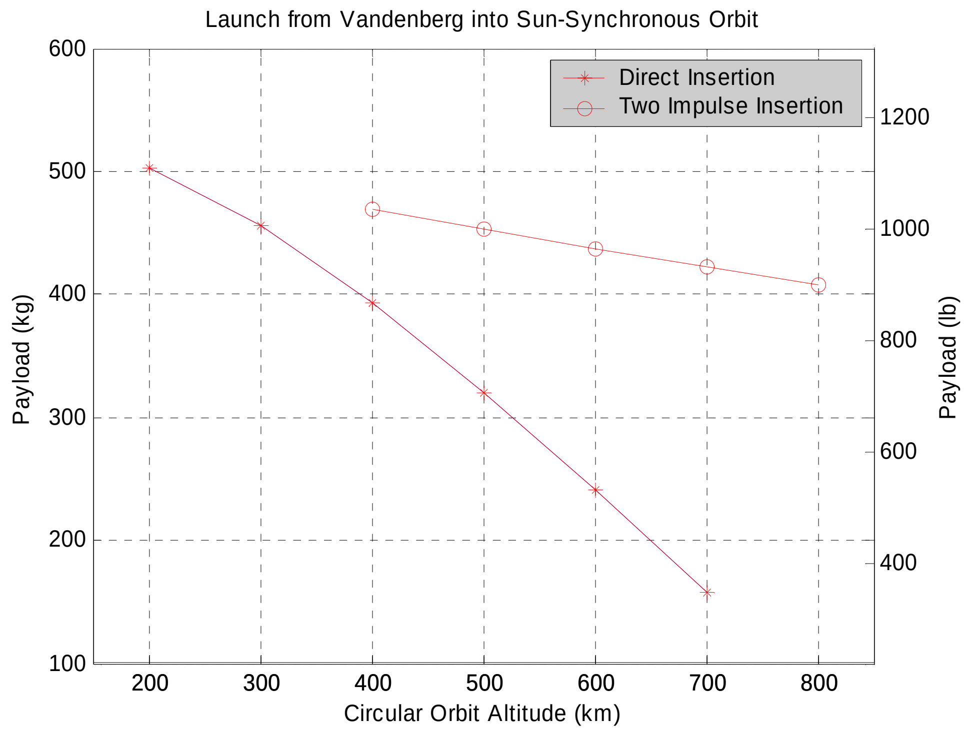

Figure 7: Falcon I Performance from Vandenberg AFB, CA

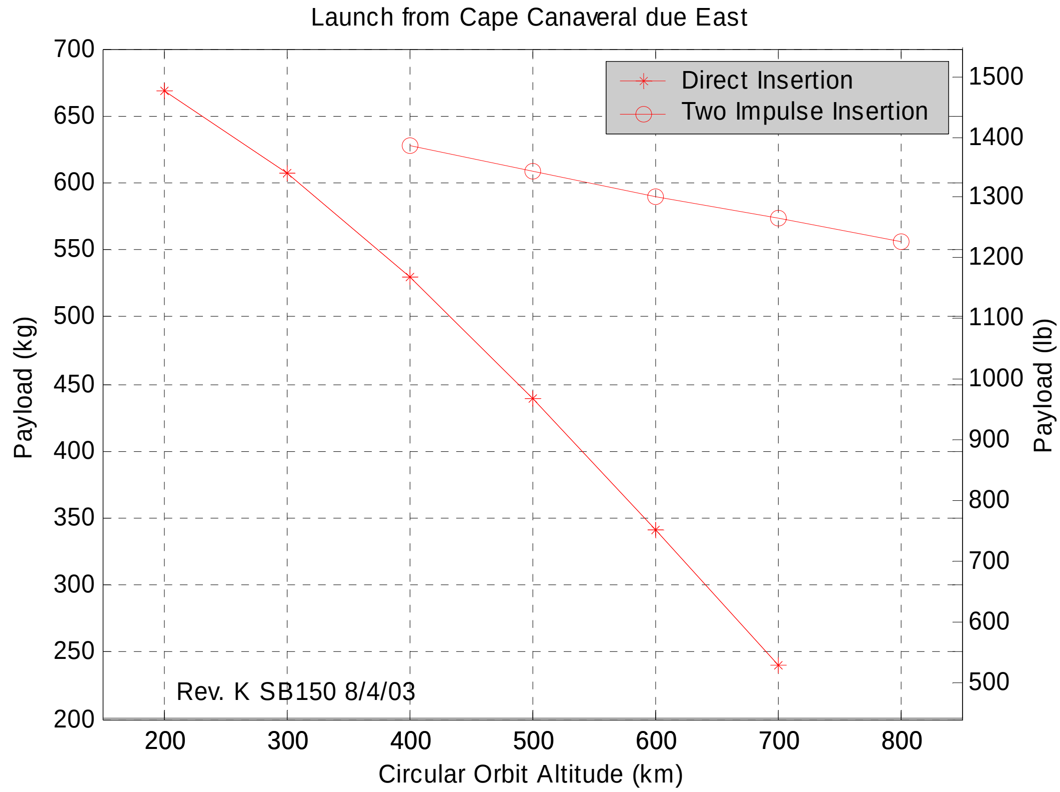

Figure 8: Falcon Performance for Circular Orbits Due East from Cape Canaveral

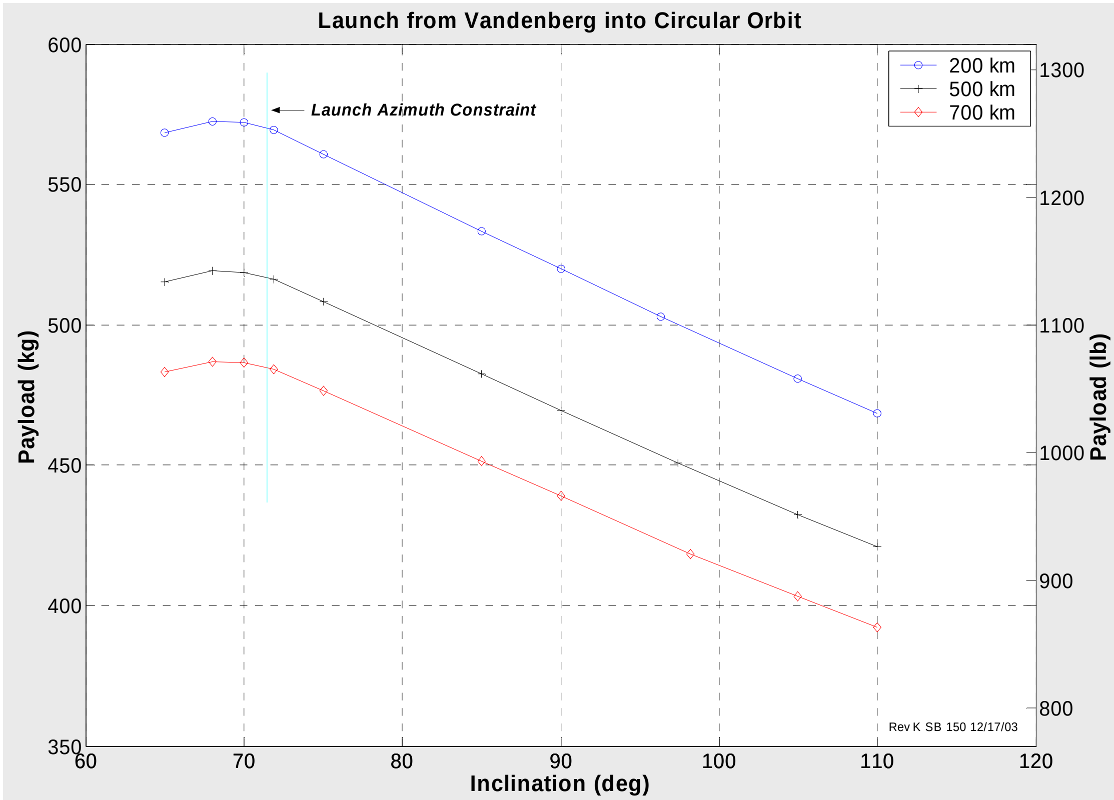

Figure 9: Falcon I Performance for Circular Orbits with Varying Inclinations

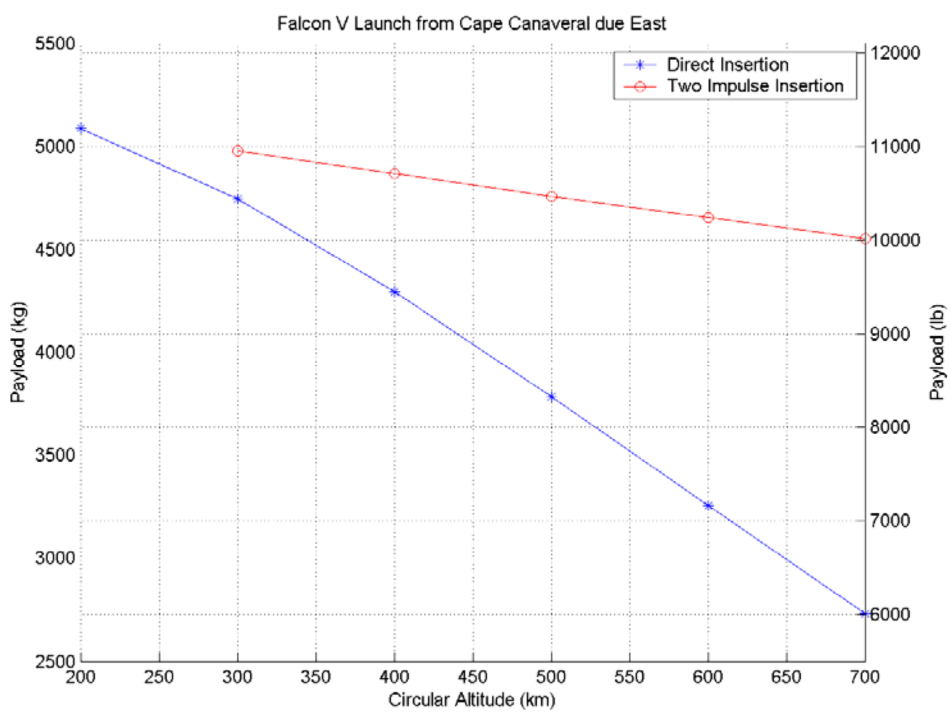

Figure 10: Falcon V Performance for Circular Orbits from Cape Canaveral

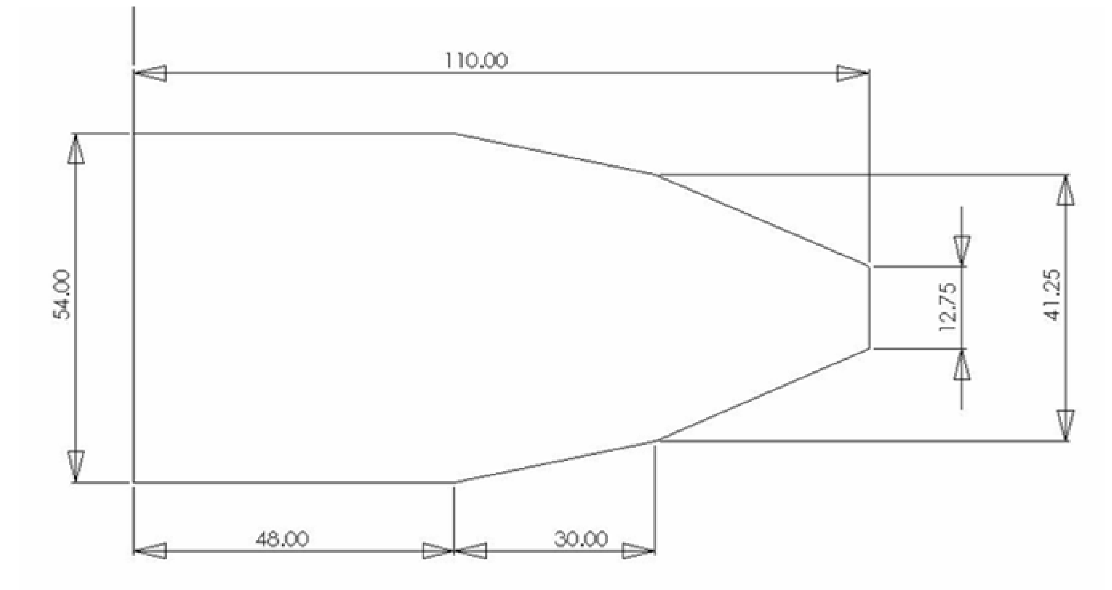

Figure 11: Falcon I Payload Volume. Dimensions are in inches

Payload Interface

Falcon was designed to provide payload customers with an extremely benign ride. Its all-liquid design with low thrust to weight ratio limits structural vibration and static loading. Acoustic blanketing is implemented which further reduces vibration and acoustic input.

In addition to a soft ride and accurate orbit injection, standard payload services include quick turnaround launch, launch site processing facilities, power and data through the T-0 umbilical, controlled environments throughout the integration process, and a controlled separation with spin-up if desired.

Falcon I can accommodate large volume payloads for its class. The useable payload volume is shown in Figure 11.

The electrical interface consists of discrete commands, an Ethernet LAN and an optional RS-232 telemetry downlink. The Ethernet is intended for ground processing and vehicle checkout and provides the ability to access the payload from virtually anywhere, given the appropriate software on board of the payload. During launch, the Ethernet is dedicated to internal communication. Also provided are pass-through cables on the launch pad for battery charging and other, payload-defined functions.

Figure 12: Kestrel Firing

Propulsion Testing

Both the first stage and the upper stage engine were designed and developed by Space Exploration Technologies. Both engines have completed development testing at our test site in central Texas. Currently, acceptance testing of flight engines and qualification testing of the engine design is on-going in Texas (Figure 12 and 13). Further testing will culminate in a vertical vehicle hold-down test, which will test the entire vehicle close to its flight configuration.

Reliability

Falcon is designed to maximize reliability by eliminating many known catastrophic failure modes at the system architecture level. The vast majority of launch vehicle failures in the past two decades can be attributed to three causes: engine, avionics and stage separation failures. An analysis by Aerospace Corporation[1] showed that 91% of known failures can be attributed to those subsystems.

[1] http://www.aero.org/publications/crosslink/winter2001/03.html

Figure 13: First Stage Engine Testing At the Space Exploration Technology Test Site in Texas

It was with this in mind that we designed Falcon I to have the minimum number of engines and separation events. As a result, there is only one engine per stage and only one stage separation event – the minimum pragmatically possible number. Moreover, the vehicle is held down after first stage ignition to verify engine operation before being released for flight. Immediate shutdown occurs if an off nominal condition is detected.

Where possible, proven and qualified components are used, such as flight qualified LOX valves. A robust qualification program is in place which includes repeated full vehicle hold down tests at our propulsion test site in central Texas. The avionics system has dual redundant IMUs and flight computers and is put through extensive hardware-in-the-loop testing. The flight computer and software are employed for every engine test, simultaneously proving the engine, electronics & software.

Status and Updates

Space Exploration Technologies provides status updates on its website (www.spacex.com) and by newsletter, distributed by email. A payload user's guide will be available for download from the website.