FAA
Commercial Space
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Experimental Permit Application for a Vertical Launch and Landing Reusable Suborbital Rocket

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Commercial Space Transportation
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TrueZer0

Experimental Permit Application

For a

Vertical Launch and Landing

Reusable Suborbital Rocket

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1. Program Description

1.1 Program Description [§437.23]

TrueZer0 is developing a suborbital launch vehicle (vehicle) with the goal of competing in the Northrop Grumman Lunar Lander Challenge (LLC) for 2008 at Holloman Air Force Base (HAFB) in New Mexico. The vehicle will be expected to launch vertically from one pad (pad A) and ascend to a height of 50m. The vehicle must then translate horizontally to position itself above an adjacent landing pad (pad B) 50m away while maintaining an altitude of at least 50m. The vehicle must then descend and land on pad B. The flight must last at least 90 seconds. During ascent, descent, and landing, the center point of the vehicle must stay within an imaginary 10m diameter cylinder centered on the pad.

1.2 Vehicle Description [§437.23(a) & §437.23(b)(1-3)]

The vehicle is a rocket designed for vertical takeoff and vertical landing. It is composed of a minimal aluminum structure joining a rocket motor, fuel tank, electronic control system, and an inert 25kg payload. The vehicle is designed to stay airborne for 90 seconds.

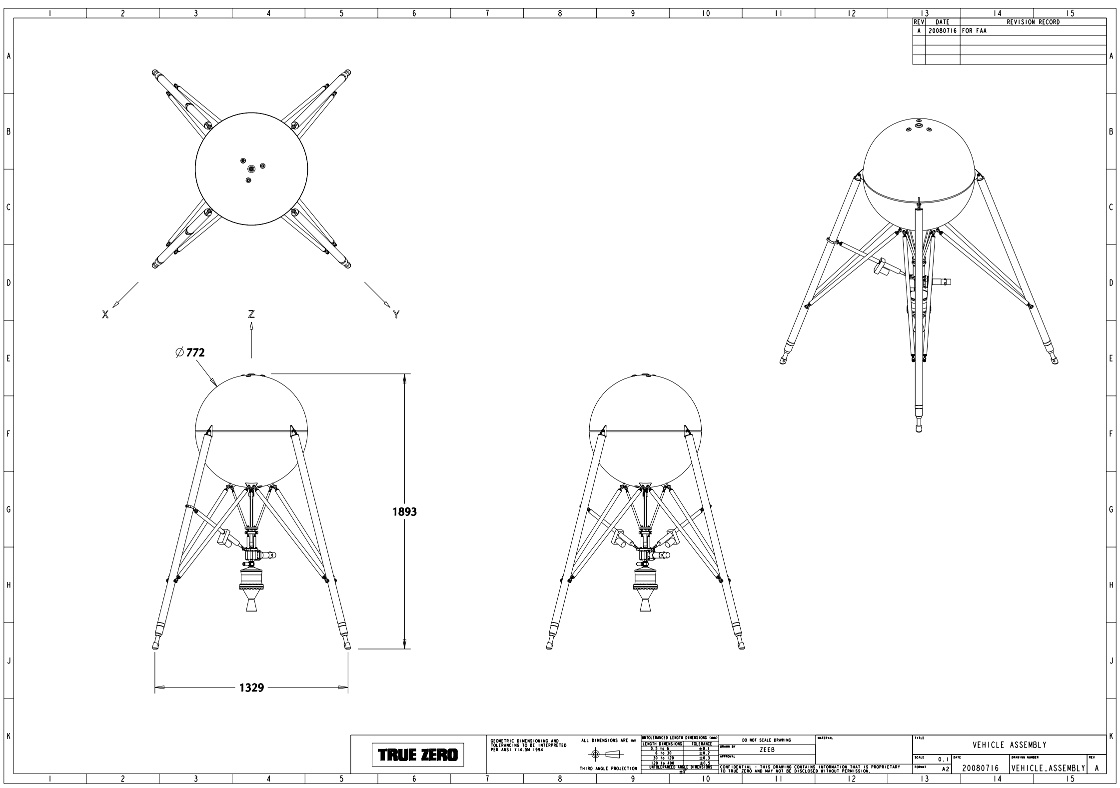


Figure 1: Vehicle Detail

Photographs of the vehicle will be added to this document as they become available. Construction of the vehicle has begun, but is not yet complete. As shown above, the vehicle footprint is about 1.4m by 1.4m. The vehicle is expected to be less than 2.2m tall. The vehicle mass should not exceed 250kg fully fueled. This mass includes the 25kg inert payload required by the LLC. See Appendix E - Vehicle Parameters. The vehicle will be tested according to the Flight Test Plan outlined in section 2.1.

1.2.1 Description of Reusable Suborbital Rocket Systems [§437.23(b)(1)]

1.2.1.1 Structural System Overview

The structure of the rocket consists of a minimal aluminum frame forming four legs. The fuel tank is used as a structural member of the vehicle. The four legs of the frame attach directly to the fuel tank. The frame and fuel tank make up the primary structures of the vehicle. The propulsion system is located beneath the fuel tank mounted between the four legs of the frame as shown in Figure 1.

1.2.1.2 Thermal System Overview

The vehicle does not require a thermal system since it is designed to operate at low speed and low altitude.

The propulsion system does not require a thermal system either. The rocket motor is fabricated from 316 stainless steel and 85% high test peroxide (HTP) is used as a monopropellant. The maximum temperature expected from the decomposition of HTP inside the motor is 910K. The stainless steel material should exhibit a yield strength of 150MPa at this temperature. The wall thickness of the motor's chamber and nozzle are sized to operate below this yield stress with a safety factor of 1.5 or more.

1.2.1.3 Propulsion System Overview

Vehicle thrust is generated by the decomposition of 85% HTP used as a monopropellant. Decomposition is achieved using a solid catalyst bed. The catalyst bed consists of about 120 stainless steel screens plated with silver, gold, platinum, rhodium and palladium. There are 25 unplated stainless steel screens at the exit of the catalyst bed to retain heat and aid in HTP decomposition.

Thrust calculations are based on the following chemical reaction for 85% HTP:

$$H_2O_2 + (0.3332)\ H_2O\ (l) \rightarrow (1.3332)\ H_20\ (g) + (0.5)\ O_2$$

The temperature inside the motor chamber is determined based on the adiabatic flame temperature for the above reaction. If the reactants begin at 298K, the products after decomposition will reach 910K. The average process temperature and specific heat ratio (gamma) for the products of the reaction are then calculated. This is an iterative process, but a solution converges quickly to $\gamma = 1.296$.

Once gamma is calculated, motor thrust is calculated based on isentropic flow of an ideal gas through a converging-diverging nozzle. The 35.10mm nozzle throat diameter is sized to achieve a maximum thrust of 2800N at a chamber pressure of 2.10MPa at a mass flow rate of 2.30kg/s.

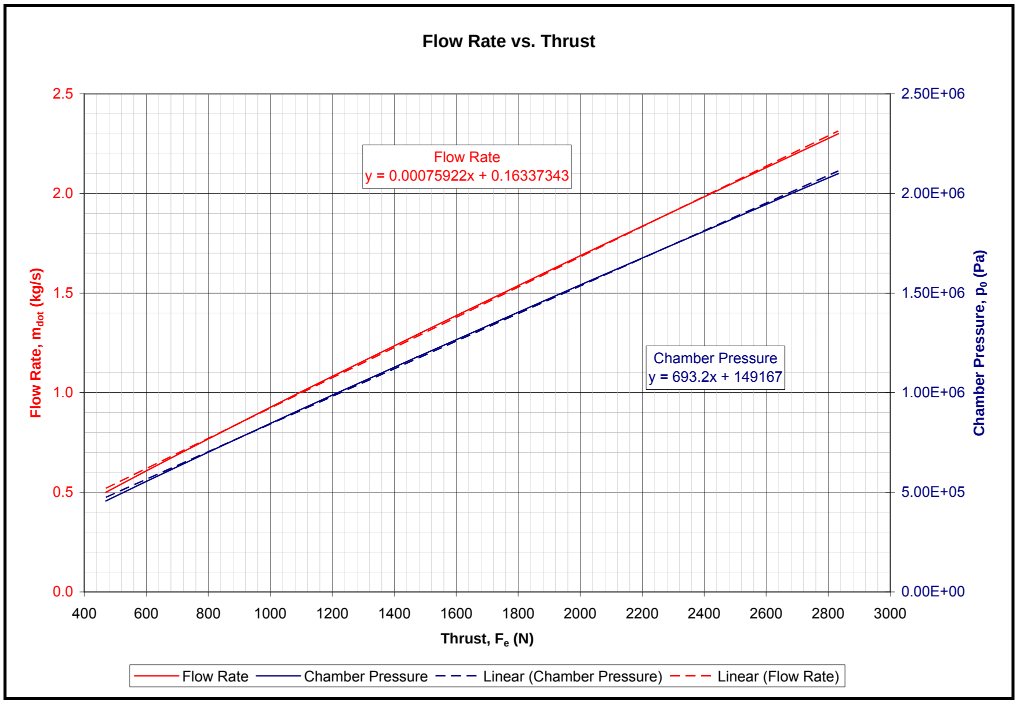


Figure 2: Theoretical Motor Performance

The diameter of the nozzle exit is 68.50mm. The exit diameter is selected to make sure the exit gasses are fully expanded prior to reaching the end of the nozzle. This means that the exiting gases are nominally over expanded. Since the motor is throttled over the course of the flight, this condition cannot be avoided.

Thrust magnitude is adjusted using an electronic servo controlled ball valve to meter the flow of HTP across the catalyst. Thrust direction is adjusted by gimballing the entire motor using electronic servo actuators.

Propellant is contained in a pressurized spherical tank fabricated from two spun 5383 aluminum hemispheres provided by AMS Industries. All other metal wetted components including valves, fittings, hoses, and motor components are made of 303, 304, or 316 stainless steel. The valve seats and seals are made from Teflon. These materials were first bathed in 85% HTP for compatibility and then further tested and verified on our motor test stand during our first static firings on June 16, 2008 and June 28, 2008 (see Flight Test Plan in section 2).

The Maximum Expected Operating Pressure (MEOP) of the tank is 3.80MPa. Static motor firings show that the pressure level in the tank is relatively immune to pressure fluctuations in the motor chamber.

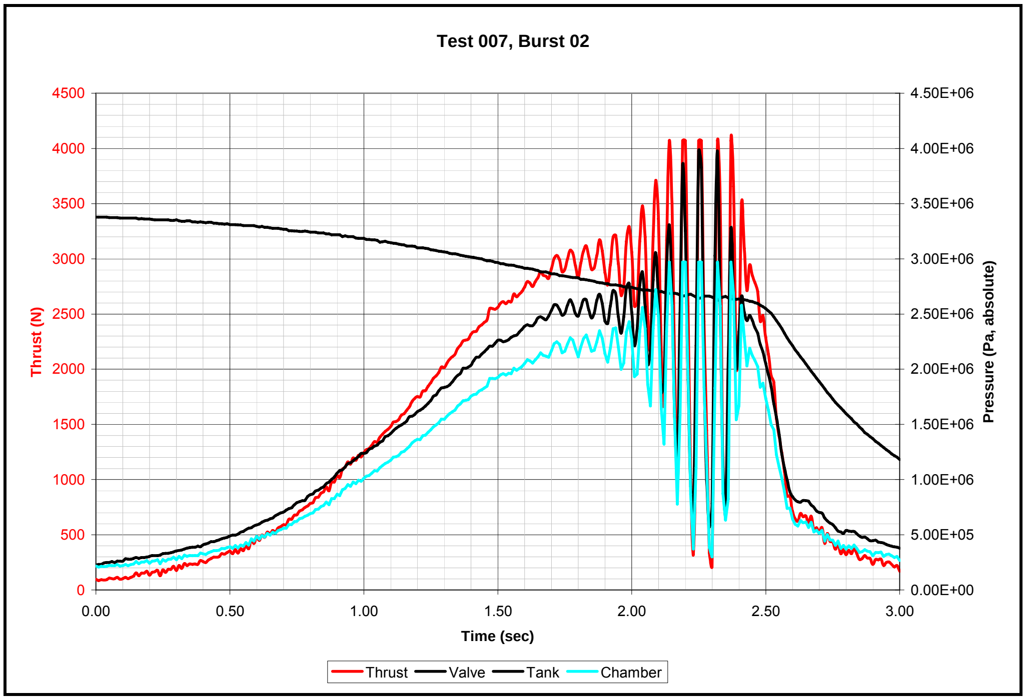


Figure 3: Static Motor Test 007 (July 28, 2008)

Further descriptions and analyses of the above plot are provided below under Motor Tests in section 2.1.

The design safety factor for the tank is 1.30 times the MEOP. This is based on a yield strength of 135MPa near the primary weld that joins the two hemispheres that form the tank. This yield strength is the minimum strength expected for 5383 aluminum in "O" condition.

The nominal wall thickness of the tank is 6.35mm. In actuality, the tank is thickest at the pole and the perimeter of each hemisphere. Care has been taken to make sure that all necessary welds on the tank are performed at these locations. This ensures that where the tank material is thin (between the pole and perimeter, the material remains in the "H116" condition with a minimum yield strength of 220MPa. Based on this, the thin areas of the tank have a design safety factor of 1.5 over MEOP.

A burst disk will be used to protect the tank from unexpected over-pressurization. The burst disk will be designed to rupture at pressure of 4.50MPa.

The tank is designed to contain approximately 100L of HTP. Prior to flight, the tank is pressurized with nitrogen. The inside diameter of the tank is 762mm, so the total tank volume is approximately 232L. The nitrogen then occupies approximately 132L at the start of the flight.

As propellant is expelled, the volume of the nitrogen increases as the volume of HTP decreases. The pressure inside the tank drops according to the volumetric expansion of the gas. The proper model for this expansion process lies between adiabatic and isothermal. Since the flight is only 90 seconds long, an adiabatic model is used. This model predicts a final tank pressure of 1.72MPa if the tank initial pressure is 3.80MPa. Actual final tank pressure will likely be slightly higher since there will be some heat transfer.

The plot below shows the estimated minimum tank pressure required to complete the 90 second mission profile with the ability to generate enough thrust to produce 1.25g accelerations at any moment. This shows that the above initial tank pressure of 3.80MPa and final tank pressure of 1.72MPa exceeds the estimated requirement.

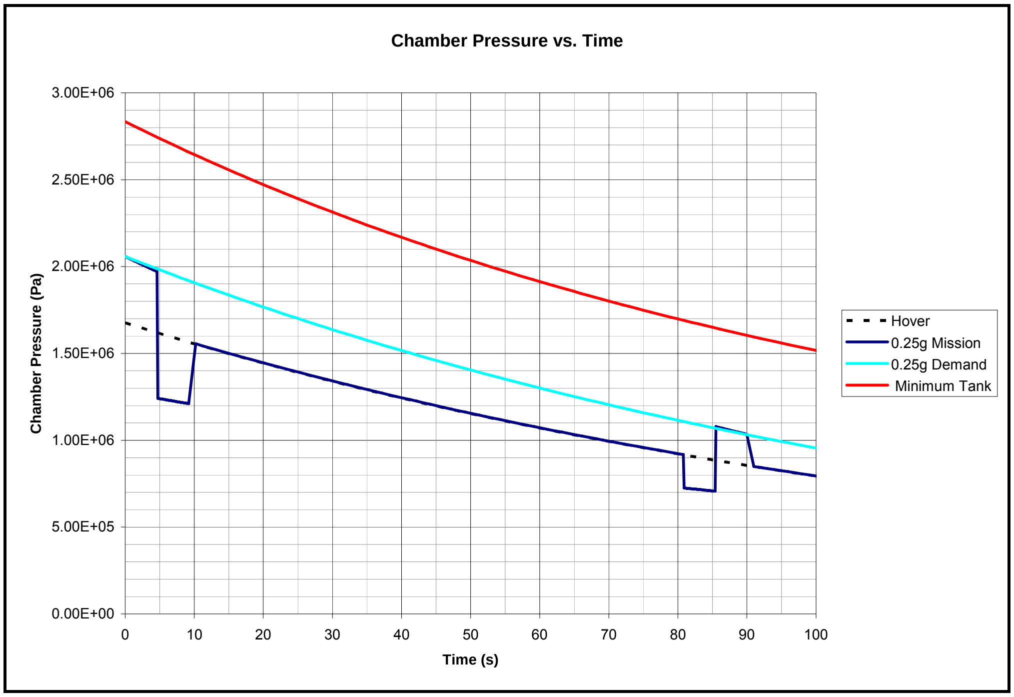


Figure 4: Estimated Minimum Required Tank Pressure

The pad operators are educated on the safe storage, transfer, and handling of 85% HTP from reading MSDS sheets provided by Peroxide Propulsion (TrueZer0's HTP supplier). The pad operators also have experience handling 85% HTP from performing static firings on our motor test stand (see Flight Test Plan in section 2). All pad operators wear a full polyethylene coated Tyvek suit, rubber gloves, rubber boots, and safety goggles. TrueZer0 follows a fueling procedure to ensure safe handling of HTP (see Appendix D - Fueling Procedure).

One pad operator is responsible for handling the HTP during fueling operations. A second pad operator is always standing by with a hose connected to a pressurized water source to dilute any spills, and rinse the HTP handler if necessary. The hose handler can also rinse any objects on the vehicle if any HTP is spilled.

The quantity of hydrogen peroxide will be measured prior to vehicle fueling operations. Each flight at the LLC will require 135 kg of HTP. This will be stored in the jerry cans provided by Peroxide Propulsion. The weight of the HTP will be measured using a scale. The weight of the jerry can itself will be subtracted during this process. Each jug is filled with 30 kg of HTP, so we will need 4.5 jugs of HTP per flight at the LLC. Since the density of 85% HTP is 1.365 kg/L, approximately 100L of HTP is required.

During permitted flights and all propulsion system tests, the tank is fueled only minutes prior to firing the motor. All fuel is expelled during each flight or test (see section 3.1.2 - Post-Flight). If there is a problem during a flight that does not allow for the fuel to be expelled through the motor, the fuel can be drained from the tank. First, a vent valve is opened, and the tank is depressurized until it reaches atmospheric pressure. The fuel tank is then drained using a ¼" ball valve at the bottom of the tank. A hose must be attached to the drain valve to pipe the HTP directly to the ground where it is flooded with water and diluted.

During flight, the amount of fuel in the tank is continuously calculated based on F=ma. The motor thrust is approximated as linearly related to the measured throttle valve exit pressure (see Figure 10: Actual Motor Performance). The acceleration of the vehicle is continuously monitored over the flight as well. Using this data, the instantaneous mass of the vehicle is calculated. The mass of fuel on board is the difference between the instantaneous vehicle mass and the dry mass of the vehicle.

The tank will have a Rapid Tank Depressurization Valve (RTDV) to terminate thrust in an emergency. This venting valve requires electrical power to open. The risk of power failure is mitigated by the fact that the safety system is electrically isolated from all other systems on the vehicle. The consequences of safety system power loss are mitigated by the fact that vehicle thrust can be terminated by either the isolated safety system or the flight control system. If the safety systems voltage drops two or more volts below nominal, the flight control system will initiate a hard abort and vehicle thrust will be terminated (see Appendix C - Checklists and Flight Rules).

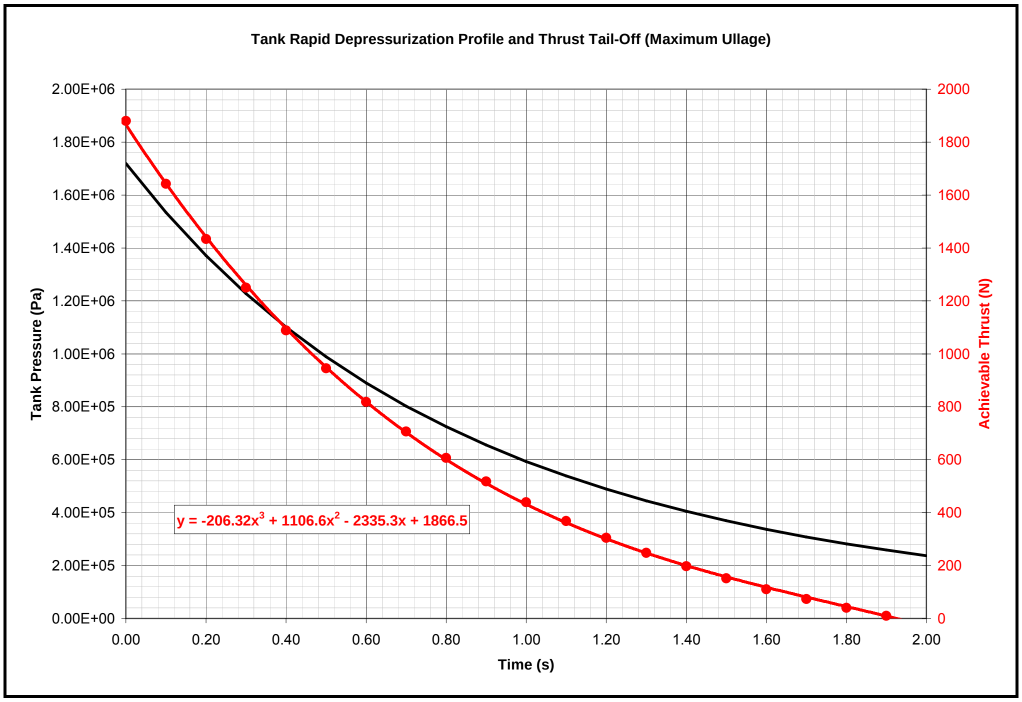


Figure 5: Thrust Tail-Off

The RTDV has a 25.4mm opening. Based on adiabatic compressible flow, it will take about 2.0 seconds for the tank to vent and for thrust to terminate. Figure 5 above shows the thrust tail-off characteristics of the propulsion system at maximum ullage.

The vehicle is equipped with two 10N attitude control thrusters. The thrusters are opposed and positioned 500mm from the “Z” centerline axis of the vehicle. These thrusters can generate about 5.0 Nm of torque to produce positive or negative spin to control vehicle attitude.

The attitude thrusters use compressed nitrogen from the vehicle’s fuel tank to produce thrust. The thrusters are actuated by two high pressure solenoid valves. The thrusters will be pulsed with the valves as necessary.

TrueZer0 believes that the demand for attitude control will be minimal since the vehicle only needs to fly for 90 seconds and there are no major forces acting to spin the vehicle. The vehicle control system is designed to tolerate a vehicle spin of 150 degrees per second and still maintain its desired flight path.

1.2.1.4 Landing System Overview

The landing system consists of four simple legs with shock absorbers affixed to the ends of each. SRAM Ario shocks (rear bicycle suspension) are used since they are very light (250g) and have adjustable spring rate and rebound. Each shock is sized to absorb the force resulting from the impact of a 225kg mass (the wet mass of the rocket) with the ground at 1.0m/s (see Structure Tests under section 2.1)

The legs and struts are designed with a minimum safety factor of 2.0 when the vehicle is fully fueled and weighs 2200N. The pressure inside the tank drops over the course of the flight as the propellant is expelled through the motor (as explained in section 1.2.1.3). At landing the weight of the vehicle is only about 880N and the pressure inside the tank is about 1.72MPa. At this pressure, the tank has a design safety factor of 2.90.

No other special systems are required since the vehicle is designed for vertical takeoff and vertical landing.

1.2.1.5 Avionics and Guidance System Overview

The avionics and guidance system is composed of a flight computer (200MHz ARM9) and three remote subprocessors (16MHz AVR). All processors communicate with each other over a CAN (Controller Area Network) bus.

The flight computer implements the control loops which manage vehicle orientation, position, and navigation.

3-axis gyro information is sampled at 100Hz. The instantaneous rotation rate provided by the gyros is used to update the flight control computer's understanding of the vehicle orientation. This information feeds an orientation control loop which is continually (100Hz) updating the gimbal mechanism in an effort to keep the vehicle upright relative to the earth.

The gimbal mechanism is only capable of rotating the vehicle along its X and Y axes. To keep the vehicle from spinning on its Z axis (which can happen if wind or other forces generate torque about the Z axis), the vehicle has two opposing attitude thrusters. Another control loop monitors Z axis rotation, and activates these thrusters to counter it.

3-axis acceleration information is sampled at 100Hz. This information is integrated to update the vehicle's velocity vector, and integrated again to update its position. Further, as GPS and altimeter data arrives (updated at 5Hz), it is blended with the accelerometer data to correct for drift, and to form a complete view of the vehicle's position and velocity relative to the earth. The resulting position, velocity, and acceleration vectors are inputs to two control loops which attempt to maintain vehicle position.

Vehicle horizontal position is maintained by providing an angular offset to the orientation control loop. To move relative to the earth, the vehicle is tilted in the desired direction of motion. This causes the vehicle's center of mass to hang out in front of the point of thrust, and this in turn causes the vehicle to accelerate horizontally.

Vehicle vertical position (altitude) is maintained by a control loop which monitors vertical position, and continuously (100Hz) adjusts the throttle valve to accelerate the vehicle to the desired altitude.

The flight control software is custom for this application, and was written entirely by TrueZer0.

The flight computer also interfaces directly with a radio modem, and manages ground communications/telemetry.

Further, the flight computer contains a data storage unit that stores all of the vehicle parameters such as position, velocity, attitude, acceleration, etc., for each flight. This data will be used to conduct the post-flight analysis as well as to support any anomaly or mishap investigations.

It should be noted that although much of this data is also sent to the ground station via the telemetry link, it is redundantly stored by the flight computer since telemetry link problems, and data rate limitations can create gaps in the recorded data as seen from the ground.

The following subprocessors are implemented:

- Inertial Measurement Unit (IMU)
- Power Systems Unit (PSU)
- Measurement and Status Unit (MSU)

The IMU subprocessor houses three orthogonally mounted MEMS (Microelectromechanical Systems) rate gyros, three orthogonally mounted MEMS accelerometers, a MEMS barometric pressure altitude sensor, and a GPS (Global Positioning System) interface.

One minute before flight, the flight computer is placed in a calibration mode. While the vehicle is stationary on the ground, the flight computer expects to be measuring angular velocities of zero on each axis. Since the gyro outputs may contain offset, the computer individually averages the outputs of each gyro, and uses the averages to counter the gyro offsets during flight.

Also, while in calibration mode, the flight computer uses the 3-axis accelerometer data to generate a vector which describes how the vehicle is tilted in the XY plane. This information initializes the vehicle's understanding of its orientation at takeoff.

The GPS receiver (which is external to the IMU) is a Garmin, model GPS 18-5Hz. The receiver and antenna are contained together in a molded plastic housing which is mounted at the nose of the vehicle, flush with the surface.

The vehicle maintains altitude and position/trajectory primarily by using the gyro and accelerometer information (which is being sampled at 100Hz). The GPS and pressure sensor data provide (relatively infrequent) 5Hz updates that the vehicle uses to correct the drift inherent in the gyros and accelerometers. If the GPS or pressure data is lost for short periods of time (less than 5 seconds), the vehicle is able to maintain trajectory and stable flight without problems. However, if the GPS or pressure data is lost for a longer period, the vehicle auto-initiates a "soft" abort sequence (see Appendix G - Aborts). This sequence is designed to put the vehicle on the ground and shut down the motor quickly -- before the data from the GPS and/or pressure sensor have become so old that the drift in the accelerometer and gyro data prevents the vehicle from being able to land in a controlled manner. It should be noted that if the autonomous soft abort sequence is not able to successfully land the vehicle in a controlled manner, ground operators will have the option to initiate a safety system trigger, or "hard" abort (see Appendix G - Aborts) at any time.

The PSU houses the power electronics which are used to control the throttle, the motor XY gimbal mechanism, and the attitude thrust solenoids.

The function of the PSU is to handle the high power switching of the 22.2V power electronics battery voltage into the motors and solenoids onboard the vehicle.

The flight computer communicates to the PSU over the CAN bus. As control loops running in the flight computer generate new gimbal requirements 100 times per second, commands are sent to the PSU telling it what voltages and polarities should be applied to the gimbal motors. New commands are sent at 100Hz, even if no changes in gimbal motor voltage or polarity are necessary.

As the flight computer generates new throttle requirements at 100Hz, commands are sent to the PSU to tell it the voltage and polarity that should be applied to the throttle valve motor. New commands are sent at 100Hz, even if no changes in throttle motor voltage or polarity are necessary.

Similarly, the flight computer sends commands to tell the PSU to open or close the solenoid valves on the attitude adjustment thrusters. New commands are sent at 100Hz, even if no changes in attitude thruster solenoid state are necessary.

The MSU subprocessor is used to measure the fuel tank pressure, throttle valve exit pressure, and the voltages and currents of the main electronics and power systems batteries.

The MSU subprocessor also monitors an optically coupled safety system heartbeat signal. This heartbeat signal consists of a periodic (10Hz) 9600bps asynchronous serial message sent across a fiber optic cable from the safety system to the MSU. If the MSU ever detects a missing or malformed message, it will alert the flight computer and a message will be sent to the ground operator. If a fault in the safety system is detected, the flight computer initiates an autonomous hard abort (See Appendix G - Aborts).

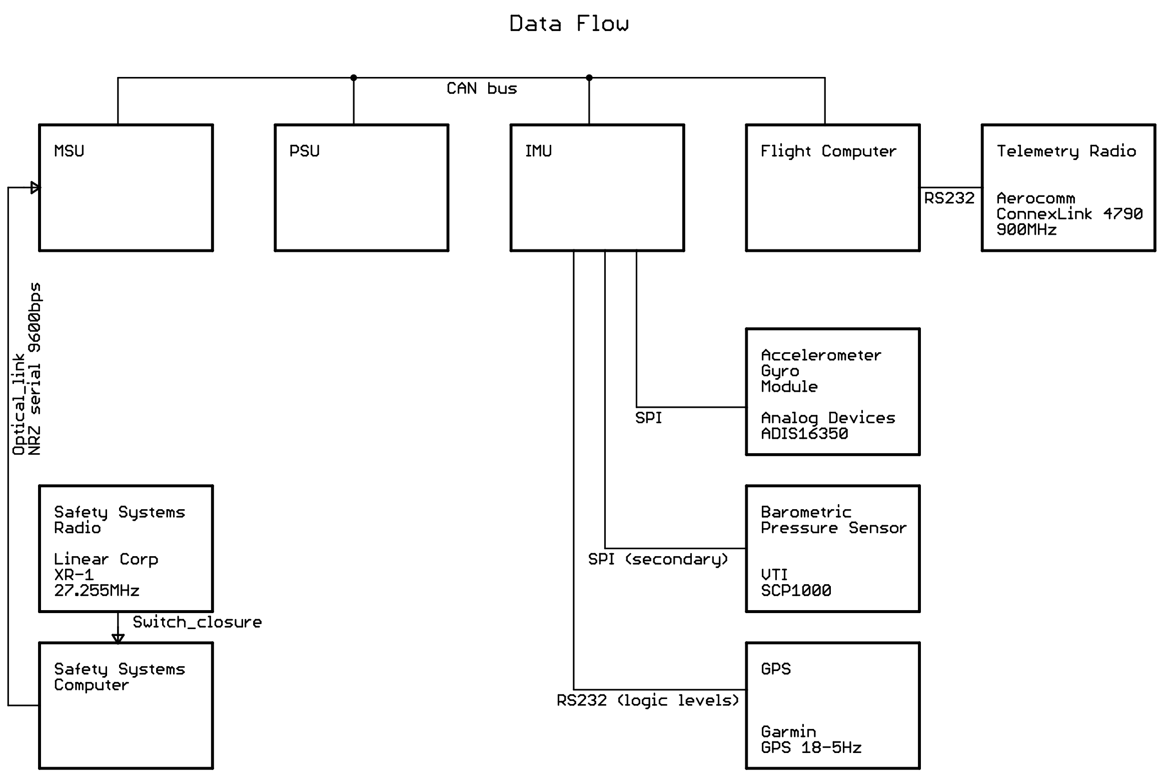


Figure 6: Data Flow

1.2.1.6 Flight Control System Overview

Vehicle flight is controlled by adjusting the following parameters:

- Throttle valve position
- Motor gimbal X axis offset
- Motor gimbal Y axis offset
- Clockwise attitude correction thruster valve open/close
- Counter-clockwise attitude correction thruster valve open/close

The throttle valve adjusts the flow of fuel fed to the motor, and is used to control the thrust of the motor. Thrust control is used to adjust/maintain the vehicle's altitude.

The motor gimbal X and Y controls are used to shift the nozzle of the motor up to +/- 11.25 degrees off center in any direction along the vehicle's XY plane. This allows the control system to torque the vehicle around the center of mass along the vehicle's X or Y axes to adjust vehicle orientation and/or flight direction.

The attitude correction thrusters are used to torque the vehicle along its Z axis to correct for any undesired Z axis rotational energy it might accumulate during flight.

The ground station sends periodic (1Hz) "pings" to the vehicle. As long as the vehicle is in communication with the ground control station (it has seen a ping within the last 5 seconds), it will attempt to maintain the trajectory last commanded from the ground. If the vehicle loses contact with the ground control station (no ping seen within the last 5 seconds), it will attempt an autonomous soft abort (see Appendix G - Aborts).

The ground control station consists of a laptop computer coupled with a radio modem.

The telemetry link is made using two Aerocomm ConnecLink 4790 radios. These are frequency hopping, spread spectrum radios capable of sending information at a maximum transmitted rate of 76.8 kpbs (half duplex). The radios contain an interface data buffer of 256 bytes. To maintain 76.8 kpbs without data loss, the maximum transmission delay is approximately 33ms in either direction.

The laptop computer receives telemetry data from the vehicle and updates a display for the Ground Flight Operator (GFO). This display updates in real time, and shows the operator the following critical parameters: current position of the vehicle, amount of fuel remaining, flight time remaining, fuel tank pressure, throttle valve exit pressure, electrical system status (voltages and currents), safety system status, and any fault which has been detected.

The GFO controls the vehicle by entering commands on a keyboard. These commands are sent to the vehicle, and instruct it to move to the various positions needed for the flight profile of the challenge.

As mentioned previously, an entirely separate one-way (ground to vehicle) radio safety system is implemented. When a safety system trigger is sent from the ground, the safety system on board the vehicle will activate the RTDV (a mechanism which immediately vents the pressure from the fuel tank). This will terminate the vehicle thrust, ending its flight. This safety system implements a "heartbeat" signal which is optically coupled to the flight control system's MSU.

The safety system radio link is made from a Linear corporation XT-1H 2W 27.255MHz hand-held transmitter, and an XR-1 radio receiver. These radios are designed to operate over a 2 mile range. The receiver's output is a simple relay / dry switch closure.

The safety system also contains an Atmel AT90CAN32 processor (running at 16MHz) which monitors the safety system battery voltage, and which transmits via an optical link, the battery voltage to the MSU at 9600bps in 1Hz intervals.

The safety system is triggered by pressing the lone button on the hand-held transmitter. This sends a signal to the receiver, and within 200ms the receiver's relay output is engaged. The safety system computer will detect this, and activate the RTDV within 10ms. Further, it will send a trigger event to the MSU within 10ms to inform it of the triggered status. The MSU will forward this information to the flight computer within an additional 10ms.

The code running in the safety system computer will be written by TrueZer0, although this has yet to be done.

1.2.1.7 Environmental Control System Overview

Not applicable. This vehicle is unmanned, and does not travel to an altitude which would necessitate environmental control for any of the systems on board.

1.2.1.8 Pneumatic/Hydraulic System Overview

No pneumatic or hydraulic system exists on the vehicle other than that described above in Section 1.2.1.3.

1.2.1.9 Electrical System Overview

A single 11.1V 2200mAh lithium polymer battery provides power for the vehicle computer systems, GPS, and telemetry radio.

Two additional series wired 11.1V 2200mAh lithium polymer batteries are used to provide 22V for all of the vehicle's power electronics (motors, valves).

Finally, a 14.8V 2200mAh lithium polymer battery is used to power the safety system radio receiver, and trigger circuit.

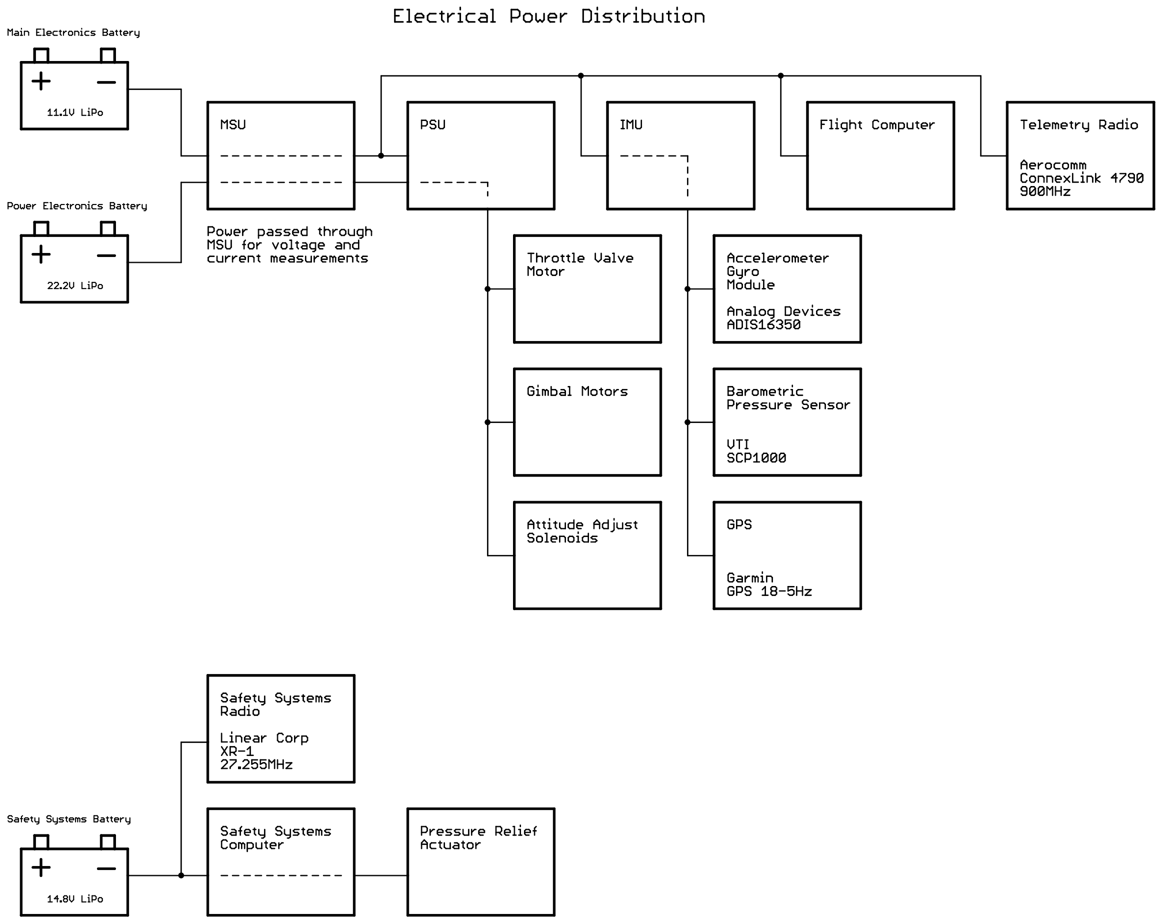


Figure 7: Electrical Power Distribution

1.2.1.10 Software and Computing Systems Overview

A list of the functional systems that contain software is provided below.

- Flight Control Systems
- Inertial Measurement Unit (IMU)
- Global Positioning System (GPS)
- Power Systems Unit (PSU)
- Measurement and Status Unit (MSU)
- Ground station display/control
- Telemetry radios
- Safety System

Not all of the software running in all of the components used on the vehicle is under the control of TrueZer0. Some software falls under the definition of commercial off-the-shelf software (COTS) as given in A.16 of FAA/AST *Guide to Reusable Launch and Reentry Vehicle Software and Computing System Safety*. For example, the software running in the GPS module was written by Garmin, and is not available for inspection by TrueZer0.

Because of this, TrueZer0 cannot completely rely on these systems to provide for the public safety.

To further protect the public, an isolated safety system is carried aboard the vehicle. This system is kept purposefully simple, and consists of a battery, a radio receiver, and a mechanism to vent pressure from the fuel tank. There is a small amount of software used to implement this component.

The software safety approaches used for this component follow the *Guide to Reusable Launch and Reentry Vehicle Software and Computing System Safety*. Specifically, when writing the code for the safety system processor, special attention is paid to fault avoidance, detection, and removal.

Fault avoidance is achieved by making a best effort to keep the complexity of the program minimized:

- Safety function implemented on a stand-alone computer
- Small number of inputs and outputs
- No memory allocation
- No interrupts
- Single thread of execution
- No recursion
- Minimal stack usage
- Only integer math
- Limited parameter passing
- All RAM cleared at startup to eliminate randomness
- Code written entirely in assembly

An inspection/review process is used to verify that the software works as expected. The safety system code running in the vehicle will always have been reviewed by at least two independent programmers. Any changes to the safety system code will be subject to the same review process.

In addition to the inspection/review process, the safety system code functionality will be tested to verify that it performs correctly under a variety of circumstances (See "Safety System Tests" in section 2).

Also, to ensure the program has not been corrupted, the safety system code will perform a self-test at each power-on which involves calculating and verifying a checksum over the entire program storage space. If the checksum does not verify, the code will not enter the main loop, and will not communicate with the MSU, preventing launch of the vehicle.

Finally, any faults that are discovered in the safety system software will be investigated, fully understood, and corrected prior to any subsequent vehicle flight.

1.3 Vehicle Purpose [§437.23(b)(4)]

The vehicle is being developed with the goal of competing in the Northrop Grumman Lunar Lander Challenge for 2008.

1.4 Payload Description [§437.23(b)(5)]

A 25 kg payload is a requirement of the competition. This payload consists of video cameras, batteries for those cameras and an inert mass.

1.5 Foreign Ownership [§437.23(c)]

TrueZer0 is 100% US citizen owned. The owners are George Johnson, Josh Johnson, Todd Squires, and Scott Zeeb.

2. Flight Test Plan

2.1 Flight Test Plan Description [§437.25(a)]

Testing is necessary to verify the ability of the vehicle electronic control and mechanical drive systems to maintain stable vertical flight as well as controlled takeoff and landing. The vehicle safety systems must also be verified.

All flight tests will have burn times of less than 15 seconds and will be performed under "amateur rocket activities" (CFR 14 Part 401.5). These tests will be performed at a decommissioned rock quarry at 3796 Harrison Rd, Rockford, Illinois 61101.

Figure 8: Flight Test Location

Tests will follow the general outline detailed below. However, the test plan may evolve as our experience with the vehicle increases. Given the early stage of development, it is difficult to predict exact dates for these tests.

Motor Tests:

TrueZer0 has fabricated a test stand specifically to test and verify motor function. This test stand uses a 12L capacity 6061 aluminum scuba tank to hold propellant. Nitrogen is used to pressurize the system. The test stand consists of a simple lever arm mounted to a pillar affixed to a base. The rocket motor is mounted to one end of the lever arm and a load cell is mounted to the other end. The load cell is used to directly measure the motor thrust since the lever pivot is symmetrically placed between the motor and load cell. The entire test stand is held down with approximately 4500N of water in two 210L drums.

Figure 9: Motor Test Stand

One pressure sensor monitors tank pressure and a second pressure sensor monitors the pressure at the throttle valve exit (between the throttle valve and the motor inlet). The vehicle will use the same pressure sensors in the same locations.

The average elevation in Rockford is 245m above see level. All calculations for motor performance are based on standard atmospheric pressure at see level. The difference in motor thrust at maximum flow rate between 0m and 145m above sea level elevation is calculated to be less than 0.4%.

To date, the following motor tests have been successfully performed on our motor test stand:

Test 001: (June 16, 2008) Thrust burst with 1.0L of HTP at 0.80MPa tank pressure
Test 002: (June 16, 2008) Thrust burst with 1.0L of HTP at 2.10MPa tank pressure
Test 003: (June 16, 2008) Thrust burst with 2.0L of HTP at 2.10MPa tank pressure
Test 004: (June 16, 2008) Thrust burst with 2.0L of HTP at 2.10MPa tank pressure
Test 005: (June 16, 2008) Thrust burst with 4.0L of HTP at 2.10MPa tank pressure
Test 006: (June 28, 2008) Thrust burst with 4.0L of HTP at 3.10MPa tank pressure
Test 007: (June 28, 2008) Thrust burst with 4.0L of HTP at 3.10MPa tank pressure

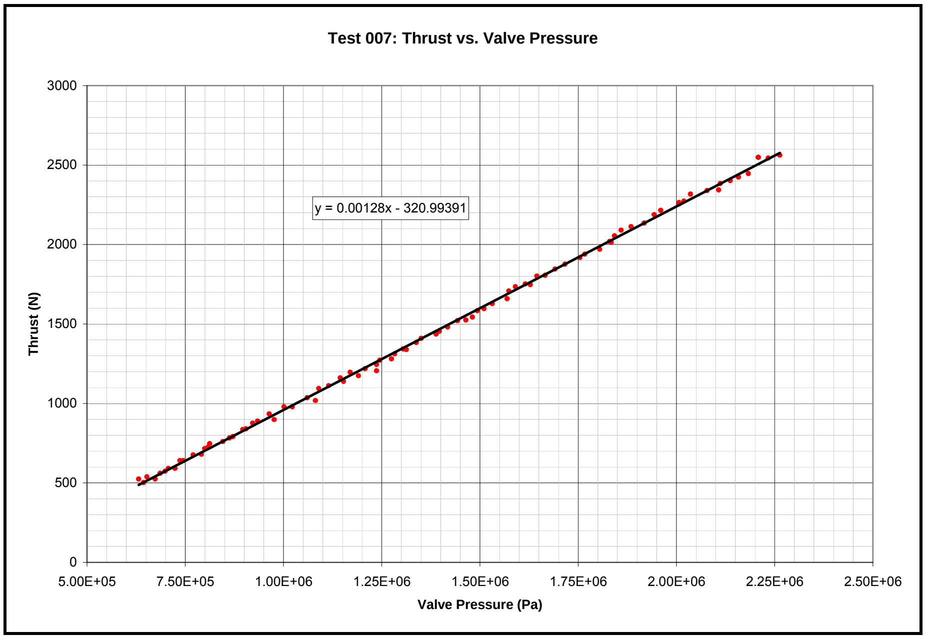


Figure 10: Actual Motor Performance

Figure 10 above and Figure 2 shown in section 1.2.1.3 summarize the above testing. The data from tests 001 through 007 was used to:

- Verify the integrity of the motor chamber and nozzle at operating pressure and temperature
- Verify throttle valve ability to feather motor thrust
- Verify correlation between throttle valve exit pressure to motor thrust (see Figure 10)
- Verify necessary tank pressure to achieve and maintain required thrust (see Figure 3)
- Verify catalyst capability to fully decompose 85% HTP while producing 2800N of thrust (see Figure 3). This implies a propellant mass flow rate of 2.30 kg/s. This will be verified in further motor tests described below.
- Determine that the fuel tank pressure must remain approximately 0.50Mpa above the throttle valve exit pressure to maintain stable thrust (see Figure 3). If this threshold is not maintained, the motor can “push back” on the incoming HTP and thrust oscillation begins. This information is used to forecast the required tank pressure of 3.80MPa at liftoff.

Once the vehicle is complete enough, the motor will be further tested during composite testing. This testing will be used to verify the following:

- Actual fuel mass flow rate versus motor thrust
- The required fuel tank pressure prior to liftoff

Fuel Tank Tests:

The fuel tank will undergo a hydrostatic pressure test to verify the strength of the 5383 aluminum material and the quality of the welds that join the two hemispheres that form the tank.

The test will be performed as follows:

- Fill the fuel tank completely with approximately 232L of water.

- Using the fuel tank's nitrogen fill port, pressurize the system to 4.56MPa (1.20 MEOP). This is done remotely with a 15m long nitrogen supply hose (see section 3.1.1 Pre-Flight).
- Close the nitrogen tank supply valve.
- Monitor the fuel tank pressure over 120 seconds for signs of pressure loss.
- Vent the fuel tank. This is done with a temporary valve located between the nitrogen tank supply valve and the fuel tank. This valve is only used for testing and will not be used on the vehicle.
- Once the fuel tank has reached atmospheric pressure, inspect the entire tank for visual signs of fluid leaks.

Flight Computer Software Tests:

This is an ongoing and more-or-less continuous process that is performed as the flight control software components are developed.

For testing the flight control software, a hardware-in-the-loop simulator was built in December of 2007. This simulator accurately models the physics of the flight environment, as well as the behaviors of all sensors, and mechanical components on the vehicle.

The flight computer hardware interfaces to the simulator in exactly the same way as it interfaces to the sensors and mechanical systems of the vehicle.

Using the simulator, it is possible to test that the flight control software (running on the actual flight hardware) performs as expected under a variety of situations that are difficult or impossible to test with the actual vehicle.

To date, the following simulations have been performed successfully (most of these are performed over and over as the software evolves):

1) Standard flight profile for the LLC level 1.
    - Verifies that the vehicle can fly for the expected 90 seconds, and can successfully maneuver from pad A to pad B and back again.
    - Verifies that the flight control software properly sends telemetry and receives commands.
    - Verifies control system stability.

2) Accelerated flight profile for the LLC level 1.
    - Verifies that the vehicle can successfully fly the accelerated LLC flight profile.

3) Wind conditions
    - Verifies that flight control software can maintain vehicle stability and position in various wind conditions.

4) GPS, gyro, and accelerometer accuracies
    - Verifies that flight control software can maintain vehicle stability and position with real-world accuracies from these devices.

5) Vehicle imbalance conditions
    - Verifies that flight control software can maintain vehicle stability and position if the vehicle becomes damaged and unbalanced.

6) Takeoff/land tilt conditions
    - Verifies that flight control software can maintain vehicle stability and position when taking off and landing in a tilted orientation.

7) Manual hard abort
    - Verifies that the flight control software will initiate a hard abort after being commanded by the GFO.
    - Verifies that the hard abort sequence is implemented correctly.

8) Hard abort boundary

- Verifies that the flight control software will initiate an autonomous hard abort if the vehicle crosses the abort boundary.

9) Hard abort velocity
    - Verifies that the flight control software will initiate an autonomous hard abort if the vehicle exceeds the hard abort velocity.
10) Hard abort due to safety system trigger
    - Verifies that the flight control software will initiate an autonomous hard abort if it detects that the safety system has been triggered.
11) Hard abort due to safety system low voltage condition
    - Verifies that the flight control software will initiate an autonomous hard abort if it detects that the safety system battery voltage is too low.
12) Hard abort due to safety system malfunction
    - Verifies that the flight control software will initiate an autonomous hard abort if it detects that the safety system has stopped communicating, or has sent a malformed message.
13) Hard abort due to MSU, PSU, or IMU inactivity
    - Verifies that the flight control software will initiate an autonomous hard abort if it loses contact with the MSU, PSU, or IMU for more than 5 seconds.
14) Soft abort landing
    - Verifies that the soft abort software is able to successfully land the vehicle.
15) Soft abort due to GPS or barometric pressure (altitude) signal loss
    - Verifies that the flight control software initiates an autonomous soft abort if the GPS or barometric pressure signal is lost for more than 5 seconds.
16) Soft abort due to telemetry signal loss
    - Verifies that the flight control software initiates an autonomous soft abort if radio contact with the ground station is lost for more than 5 seconds.
17) Hard abort during soft abort
    - Verifies that the vehicle will always initiate the hard abort sequence correctly, even while it is performing a soft abort.

Once the vehicle hardware is complete enough, the flight control software will be tested in real-world situations (see composite tests).

Flight Computer Hardware Tests: (sensors, boards, etc.)

The following flight computer hardware components have been tested:

Flight computer main processor board:

This is an off the shelf 200MHz ARM9 based single board computer:
TS-7250 from Tehnologic Systems
http://www.embeddedarm.com/products/arm-sbc.php#ts-7200-series
The board runs Linux in a stand-alone mode, and has been used to test the flight software against the hardware-in-the-loop simulator since March 2008. In that time, it has worked well, and shown no signs of instability.

500 psi pressure sensors:

The pressure sensors used on the vehicle are the same as those that were used on the motor test stand for motor tests 001 through 007. During the motor tests, the pressure sensors worked as expected (see Figure 3 and Figure 10).

MSU, PSU, IMU, safety system boards:

These are all based on a custom Atmel AVR AT90CAN32 board design. This board design has been used in a number of projects, and has shown itself to be reliable and trouble free. The actual MSU, PSU, IMU, and safety systems processor boards have been bench tested, and are working cleanly in that environment.

Telemetry radios:

The telemetry/control radio link is implemented with a pair of off the shelf ConnexLink 4790-1000 1 Watt spread-spectrum (902-928MHz) radios from Aerocomm (www.aerocomm.com). These radios have been tested over a limited range (about 50 meters) so far, and appear to have acceptable performance. They will be tested at a distance of 300 meters before any permitted vehicle flights are made.

The following flight computer hardware components have not been tested:

Safety systems radios:

The safety system trigger radio link will be implemented using a Linear corporation 27.255MHz 2 Watt transmitter/receiver pair (XT-1H/XR-1). These radios have been ordered, but have not yet arrived. They are spaced to have a range of about 2 miles line-of-sight.

Once the vehicle is complete enough, all flight control hardware will be tested in real-world situations (see composite tests).

Electromechanical Systems Tests:

There are 4 electromechanical systems on the vehicle -- the throttle valve servo, the gimbal servos, the attitude solenoids, and the safety system RTDV. These systems are currently being constructed, and have not yet been tested.

Each system will be ground tested (tentatively scheduled in August) once it has been mounted to the vehicle. The ground testing will involve actuating the system, running it through its full range of motion, verifying that the current draw from the batteries is within acceptable limits, and verifying that the system performs to design requirements.

For the throttle valve, the design requirements are:

- Full close to full open in 0.5 seconds
- Full open to full close in 0.5 seconds
- Maximum current draw of 5A @ 22.2V, average <2A

For the gimbal servos, the design requirements are:

- 11.25 degrees of motor nozzle displacement either side of center
- Negative 11.25 to positive 11.25 degree displacement in 0.5 seconds (both axes)
- Positive 11.25 to negative 11.25 degree displacement in 0.5 seconds (both axes)
- Maximum current draw of 5A @ 22.2V per axis, average <2A

For the attitude thrust solenoid valves, the design requirements are:

- Maximum current draw of 5A @ 22.2V per valve, average <2A

For the safety system RTDV, the design requirements are:

- Must operate reliably at voltages of 12.0V-15.0V
- Maximum current draw of 5A @ 14.8V
- Safety vent fully closed to fully open in <0.5 seconds

Structure Tests:

The structure of the rocket will be tested by conducting a series of vehicle drop tests. During each test, the vehicle will be dropped from a height of 50mm to simulate an impact with the ground at 1.0m/s. The force of the impact will be calculated based on the vehicle weight and the acceleration data from the vehicle's accelerometers. The entire vehicle will be visually inspected for damage after each test, but the following items will be specifically checked:

- Fuel tank

- Legs and struts
- All mechanical joints
- Shock absorbers
- Electrical components
- Safety system RTDV

The following specific tests will be conducted:

- Drop the vehicle with no fuel and with an unpressurized fuel tank.
- Drop the vehicle with 135kg of distilled water with an unpressurized fuel tank.
- Drop the vehicle with 135kg of distilled water with the fuel tank pressurized to 3.80Mpa (MEOP).

Note: The vehicle is expected to carry 135kg of HTP at liftoff. The volume of water will be 135L instead of 100L since 85% HTP has a density of 1.365kg/L.

Safety System Tests:

The entire safety system (radios, control processor, power electronics, RTDV, optical data link to MSU) will be ground tested (date TBD) once the vehicle has reached the necessary stage of development. The test will involve the following steps:

- Power up the system, verify it is communicating correctly with the MSU.
- Disrupt communications to the MSU by removing the fiber optic cable. Verify that the MSU notices within two seconds.
- Change the supply voltage to the safety system throughout the range of 12V to 15V. Verify that the battery voltages reported to the MSU are always accurate to within 0.2V.
- When the supply voltage falls below 12.8V, verify that the flight computer triggers a hard abort.
- Position the transmitter 1.5 miles line-of-site from the receiver, and verify that the safety system can be reliably triggered at voltages ranging from 12.0V to 15.0V.

NOTE: the complete safety system will never be tested in an untethered flight since this would result in a vehicle crash.

Composite Tests:

The following composite tests will be performed to verify the performance of the entire vehicle:

Static tests:

The vehicle will be securely restrained to the ground. The vehicle will undergo bursts of thrust (lasting less than 15 seconds). The vehicle will be fueled and pressurized according to TrueZer0's pre-flight checklist (Appendix C) and fueling procedure (Appendix D). The safety system abort will be triggered and the tank pressure will be monitored over time. The vehicle will be made safe at the end of the tests according to TrueZer0's post-flight checklist (Appendix C).

The tests should verify the following:

- Pre-flight and post-flight checklist efficacy
- Fueling procedure efficacy
- Motor performance
- Electromechanical system performance
- Structural system performance
- Safety system performance
- Tank pressure profile over motor firing
- Tank pressure profile over safety system depressurization
- Motor thrust initiation (key flight safety event)

Low altitude tethered hover tests:

The vehicle will be restrained to a maximum altitude of 1m above the ground. The vehicle will undergo a short (less than 5 seconds) vertical takeoff and landing within the 1m envelope. Pre-flight and post-flight operations will be followed as above during static firings.

In addition to the verifications from static tests, these tests should verify the following:

- Electronic control system performance
- Electromechanical system performance
- Vehicle lift-off (key flight safety event)
- Vehicle landing (key flight safety event)

Medium altitude tethered flight tests:

The vehicle will be suspended from a 3m long tether affixed to a telescopic forklift. Liftoff will be from a platform 1.0m tall. The platform will be removed after liftoff. Vehicle flight durations will be 15 seconds or less. This will be the first time that all vehicle functions will be tested. The ground control station will be located 125m away from the vehicle to make sure that the telemetry radios work as expected over that range. During permitted flights, the control station will be approximately 100m away from the pads (see Figure 13 and section 3.1.1 Pre-Flight). Pre-flight and post-flight operations will be followed as above during static firings.

In addition to the verifications from previous composite tests, these tests should verify the following:

- Vehicle ascent (key flight safety event)
- Vehicle translation (key flight safety event)
- Vehicle hover (key flight safety event)
- Vehicle decent (key flight safety event)

Untethered flight tests:

The vehicle will be unrestrained and will complete a reduced mission profile lasting less than 15 seconds. This includes a vertical takeoff, horizontal translation, and vertical landing. The maximum altitude is not expected to exceed 5 meters. Pre-flight and post-flight operations will be followed as above during static firings. TrueZer0 will follow its flight rules for all untethered tests (see Appendix C - Checklists and Flight Rules).

In addition to the verifications from previous composite tests, these tests should verify the following:

- Vehicle’s ability to maintain its mission profile
- Flight rules
- Ground crew competency (the ground crew includes Pad Operations, the GFO, and the STO)

2.2 Description of Proposed Operating Area(s) [§437.25(b-c)]

The LLC rules require a 90 second demonstration flight as a prerequisite to compete. TrueZer0 plans to perform this demonstration flight at Holloman Air Force Base (HAFB). The specific date of this demonstration flight is TBD, but will preferably be scheduled for the week of October 20th, a few days before the competition. Depending on the actual demonstration flight date, the availability of HAFB, and when the experimental launch permit process is complete, TrueZer0 may need a burn time waiver of 100 seconds in order to perform this flight.

All remaining flights exceeding 15 seconds will occur at the LLC. The figure below shows the pads and operating areas at the LLC:

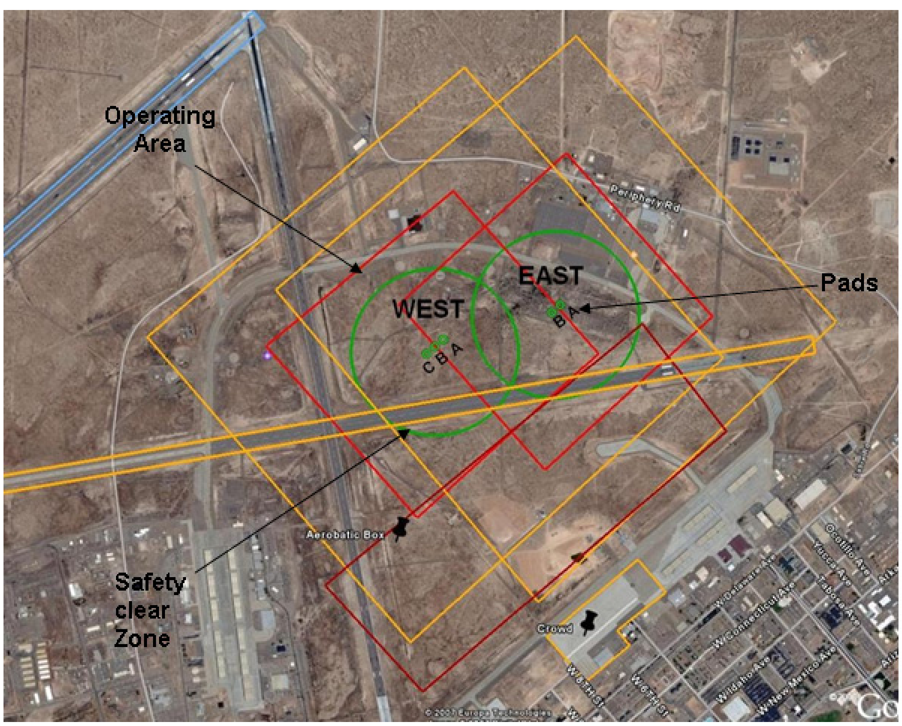


Figure 11: LLC Operating Area

The GPS coordinates for the pad locations are:

- East Pad A: 32° 51' 15.402"N, 106° 05' 33.016"W
- East Pad B: 32° 51' 14.312"N, 106° 05' 34.439"W
- West Pad A: 32° 51' 10.321"N, 106° 05' 52.886"W
- West Pad B: 32° 51' 09.244"N, 106° 05' 54.324"W
- West Pad C: 32° 51' 08.167"N, 106° 05' 55.763"W

The dimensions of the zones and areas shown in the Figure 11 are:

- Safety Clear Zone: 1250 ft radius
- Operating Area: 1640 ft (~500m) radius (box 3445 ft by 3289 ft)
- Flight Hazard Zone: 3000 ft (box 6070 ft by 5906 ft)

3. Operational Safety Documentation

3.1 Pre-Flight and Post-Flight Operations [§437.27 & §437.53(a-b)]

3.1.1 Pre-Flight

To prepare for a flight, the GPS coordinates of both the takeoff and the landing points will need to be known. For the LLC, these points are two pads, designated A and B. An operator with a laptop and a GPS receiver will first go to the takeoff point, place the GPS at the center, and take a reading. Then the operator will move to pad B and do the same.

These readings will be loaded into the vehicle's flight system, setting the parameters for the flight.

Prior to any flights, the vehicle will be held in a staging area. While in this area, the vehicle's electrical and mechanical systems will be tested and verified to be in proper working order.

The vehicle will be transported to pad A when permission is given. Once at the pad, a safety inspection will be performed. The vehicle will be examined for any visual signs of trouble. The throttle valve will be verified to be closed and the vehicle's telemetry and safety radio antennas will be checked. Note: The vehicle's electrical system will be in an "off" state during all inspections and fueling operations.

Once the inspection is complete and the vehicle looks good to fly, the vehicle is ready to be fueled. Everyone but the pad operators, the Safety Trigger Operator (STO), and the GFO must be cleared from the operating area. From this point forward, the status of the operating area will be routinely monitored and verified to be clear of non-essential people. See Appendix C - Checklists and Flight Rules.

TrueZer0 has chosen not to define a "safety clear zone" since there will likely only be minutes between hazardous pre-flight operations and actual flight. Since actual flight will require the operating area to be clear, defining a "safety clear zone" is somewhat redundant.

Since the vehicle uses HTP as a monopropellant, fueling is relatively straightforward (see fueling procedure shown in Appendix D). The fuel cap is located at the top of the tank. The fuel cap will be removed and a funnel will be placed in the fill spout. HTP will be poured directly from its 30kg storage jug into the tank. As discussed in section 1.2.1.3 Propulsion System Overview, the proper amount of HTP will be measured prior to the fueling operation. Once the proper amount of fuel is transferred to the tank, the fuel cap will be reinstalled. The status of the area around the vehicle is now a Class 5.2 (Organic Peroxide Oxidizing Agent) hazard.

Next the vehicle is powered on and a pre-flight self test is performed. This test will involve verifying that vehicle batteries are charged, that communications with the vehicle are working, and that there are no faults of any kind being reported by the vehicle's flight or safety systems. If no faults are reported, the tank is ready for pressurization.

The tank is pressurized remotely for the safety of the pad operators. The tank is equipped with a check valve and a quick disconnect plug. One end of the remote hose is connected to the nitrogen supply tank located 15 meters away in the service vehicle. The supply tank is equipped with a supply valve, a pressure regulator, and a purge valve. The other end of the remote hose has a quick-disconnect socket with a cable attached to the release sleeve for remote actuation.

First, the supply hose is connected to the tank with the quick-disconnect fitting. The ground operators then move to the service vehicle (still 15 meters away). The operating area is again verified to be clear of all non-essential people. Once the area is verified to be clear, pressurization can begin. The supply valve is opened and the tank is brought to its operating pressure. The supply hose purge valve is then opened to depressurize and vent the hose. The supply hose is then disconnected from the tank by pulling the cable attached to the sleeve of the quick-disconnect. Lastly the hose is withdrawn from the pad area and tank pressurization is complete.

Tank pressure will be monitored with the ground control station in the service vehicle to ensure that there are no leaks in the propulsion system and that the proper tank pressure was achieved.

Pad operations personnel join the GFO in the service vehicle and move to a location approximately 100m from pad A and pad B (see Figure 13). Next the STO moves into position immediately outside the vehicle to visually monitor the abort boundary and the performance of the vehicle. The GFO then makes sure the STO is ready and verifies their status. The STO visually verifies that the operating area is clear of all non-essential people. The GFO verifies that the meteorological conditions are met and obtains permission to launch from event control. If the operating area is clear and permission to launch is given, the vehicle is ready for liftoff.

3.1.2 Post-Flight

Once the vehicle has successfully landed, it will be commanded to open the throttle valve just enough to spend the remaining fuel, but not generate thrust in excess of 400N. This safely disposes of any remaining fuel and vents the remaining tank pressure.

Once the telemetry indicates atmospheric tank pressure, the throttle valve will be fully opened to prevent any self-pressurization of the tank. It is now safe for the ground crew to approach the vehicle. The tank cap will be removed to further guarantee that the tank remains at atmospheric pressure. This marks the end of hazardous post-flight operations. The vehicle will then be prepared for another flight or be transported back to the vehicle staging area.

For further details, see Appendix C - Checklists and Flight Rules.

3.2 Hazard Analysis [§437.29 & §437.55(a)]

TrueZer0's hazard analysis process consists of four parts:

1) Identifying and describing the hazards,
2) Determining and assessing the risk for each hazard,
3) Identifying and describing risk elimination and mitigation measures, and
4) Validating and verifying risk elimination and mitigation measures.

Our assessment of the risks is a qualitative process. Risk accounts for both the likelihood of occurrence of a hazard and the severity of that hazard. The levels for the likelihood of occurrence of a hazard, presented in Table 3.2, and the categories for the severity of a hazard, presented in Table 3.1, were used in combination with the four-step hazard analysis process to develop our list of hazards. The severity and likelihood are combined and compared to criteria in a risk acceptability matrix, as shown in Table 3.3. The following FAA/AST guidance document is used to perform its hazard analysis: AC 437.55-1, *Hazard Analysis for the Launch or Reentry of a Reusable Suborbital Rocket Under an Experimental Permit*.

As our flight test program progresses, there will be anomalies that will be credited to component, subsystem, or system failures or faults; software errors; environmental conditions; human errors; design inadequacies; and/or procedural deficiencies. As these anomalies occur during our program, a risk elimination/mitigation plan will be developed. In addition, TrueZer0 will provide verification evidence (i.e., test data, demonstration data, inspection results, and analyses) in support of our risk elimination/mitigation measures. Our hazard analysis will be continually updated as our test program progresses. See Appendix A for a list of the identified hazards. Appendix B provides a description of our verification schedule.

Table 3.1 Severity of Hazard

Description	Category	Consequence Definition
Catastrophic	I	Death or serious injury to the public or safety-critical system loss.
Critical	II	Major property damage to the public, major safety-critical system damage or reduced capability, decreased safety margins, or increased workloads.
Marginal	III	Minor injury to the public or minor safety-critical damage.
Negligible	IV	Not serious enough to cause injury to the public or safety-critical system damage.

Table 3.2 Likelihood of Occurrence of Hazard

Description	Level	Individual Item
Frequent	A	Likely to occur often in the life of an item, with a probability of occurrence greater than 10^{-2} in any one mission.
Probable	B	Will occur several times in the life of an item, with a probability of occurrence less than 10^{-2} but greater than 10^{-3} in any one mission.
Occasional	C	Likely to occur sometime in the life of an item, with a probability of occurrence less than 10^{-3} but greater than 10^{-5} in any one mission.
Remote	D	Unlikely but possible to occur in the life of an item, with a probability of occurrence less than 10^{-5} but greater than 10^{-6} in any one mission.
Extremely Remote	E	So unlikely, it can be assumed occurrence may not be experienced, with a probability of occurrence less than 10^{-6} in any one mission.

Table 3.3 Risk Acceptability Matrix

Severity / Likelihood	Catastrophic I	Critical II	Marginal III	Negligible IV
Frequent (A)	1	3	7	13
Probable (B)	2	5	9	16
Occasional (C)	4	6	11	18
Remote (D)	8	10	14	19
Extremely Remote (E)	12	15	17	20

Category 1 – High (1-6, 8). Elimination or mitigation actions must be taken to reduce the risk.
Category 2 – Low (7, 9-20). Risk is acceptable

3.3 Operating Area Containment

3.3.1 Methods of Containment [§437.31 & §437.57(a)]

The vehicle is contained within the operating area by two independent mechanisms:

1) The ground control station issues commands to the vehicle flight control system to direct its path, and keep it within the operating area.

2) The vehicle will carry a safety system which is independent of all other systems on the vehicle. With the press of a single button (the safety system trigger) the safety system will allow the STO to depressurize the vehicle's fuel tank, terminating any thrust from the vehicle's motor.

During flight, the vehicle's position is monitored at all times. If the vehicle crosses the abort boundary shown in Figure 12, the STO, the GFO, and the flight computer will abort the flight.

Further, the velocity of the vehicle is measured at all times during flight. If the vehicle's velocity ever exceeds 10m/s, the STO, the GFO, and the flight computer will abort the flight.

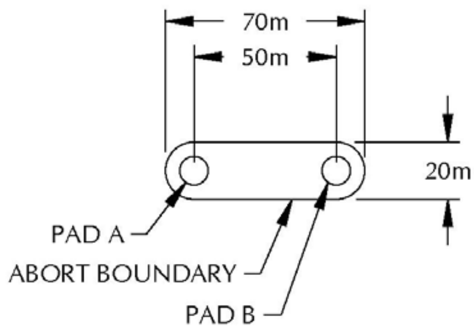


Figure 12: Abort Boundary Detail

The abort boundary is further defined by a horizontal plane 70m above the ground.

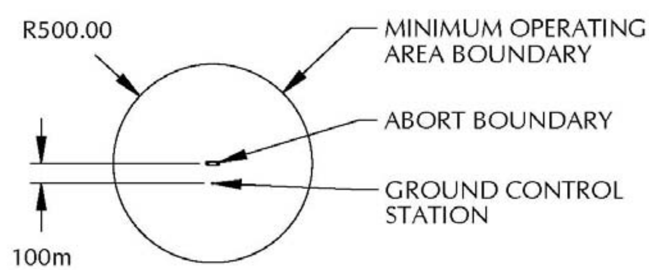


Figure 13: Minimum Operating Area

The operating area is defined based on the maximum velocity the vehicle can achieve during an abort. The maximum velocity is determined based on a 2.4 second reaction time for the STO and the thrust tail-off characteristics of the propulsion system during a safety system abort. The instantaneous impact point of the vehicle will not extend beyond the minimum operating area shown in Figure 13. See Appendix F - Minimum Operating Area Calculation for specific details.

3.3.2 Population [§437.31(a) & §437.57(b)]

The 2008 LLC will be held at Holloman Air Force Base in New Mexico. TrueZer0 will update this application as soon as population data is provided by the LLC.

3.3.3 Significant Traffic [§437.31(a) & §437.57(b)]

The operating area will not contain significant automobile traffic, railway traffic, waterborne vessel traffic, or large concentrations of the public.

3.4 Key Flight-Safety Event Limitations

3.4.1 Key Flight-Safety Events [§437.31(b) & §437.59(a)]

As described in section 2.1, our flight test plan is incremental. For the vertical launch tests at the LLC, the key flight-safety events are:

- Motor thrust initiation
- Liftoff
- Ascent
- Translation
- Descent
- Hover
- Landing

All key flight-safety events will be located within the operating area defined by the LLC.

The verification evidence for the methods and systems used to conduct key flight-safety events is detailed in Appendix A - Hazard Analysis.

3.4.2 Reentry Impact Point [§437.31(b) & §437.59(b)]

The abort procedures and safety systems used to ensure the vehicle remains within the operating area will be verified during testing according to our verification schedule shown in Appendix B.

3.5 Landing and Impact Locations [§437.33 & §437.61]

During normal operation, the vehicle will land on the A and B pads defined by the LLC. In the event of a failure leading to an abort of the flight, all impact locations will be within the operating area. See Figure 12: Abort Boundary Detail and Figure 13: Minimum Operating Area.

3.6 Agreements [§437.35 & §437.63]

TrueZer0's application for Registration in the 2008 Lunar Lander Challenge was accepted by the XPF on July 17, 2008. TrueZer0 will provide a copy of the agreement as soon as it is available.

3.7 Collision Avoidance Analysis [§437.65]

A collision avoidance analysis is not required from United States Strategic Command or Federal launch range since our maximum altitude of 70m is lower than the FAA threshold of 150 km.

3.8 Tracking a Reusable Suborbital Rocket [§437.37 & §437.67]

The vehicle's telemetry stream will contain real time readings of the GPS latitude, longitude and altitude. This telemetry data will be recorded by the ground station.

In addition, the vehicle's flight computer contains a data storage unit that stores the readings of all of the vehicle parameters such as position, velocity, attitude, acceleration, etc., for each flight.

This data will be archived in compliance with the operating rules of §437.67 and made available to the FAA.

3.9 Flight Rules

Flight rules constitute the basis of TrueZer0's safety procedures. The complete list of rules is shown in Appendix C - Checklists and Flight Rules.

3.9.1 Pre-Flight Checklist [§437.39 & §437.71(a)]

TrueZer0 will follow its Staging Area Checklist and its Pre-Flight Checklist shown in Appendix C - Checklists and Flight Rules before initiating any rocket powered flight.

3.9.2 All Phases of Flight [§437.39 & §437.71(b)]

During all phases of flight, TrueZer0 will adhere to its flight rules. If at any time the vehicle is in a state that could endanger the uninvolved public, the ground crew will abort the flight. See Appendix C - Checklists and Flight Rules.

3.10 Mishap Response [§437.41 & §437.75(b)]

Todd Squires of TrueZer0 will be the point-of-contact and Scott Zeeb the alternate for all activities associated with accidents, incidents, or other mishaps related to operations at the LLC. The designated point-of-contact and/or alternate will:

- Represent the vehicle operator as a member of the Emergency Response Team (ERT) and support the LLC's Emergency Response Coordinator (ERC) by participating in the activities of the ERT during accidents, incidents, or mishaps.
- Ensure that the consequences of a mishap are contained and minimized.
- Assure that all data and physical evidence related to any accident, incident, or mishap is impounded to preclude loss of information essential to subsequent investigations.
- Identify and adopt preventive measures for avoiding recurrence of the event.
- Through the LLC's ERC, report to and cooperate with FAA and National Transportation Safety Board (NTSB) investigations and act as the vehicle operator point-of-contact for the FAA and NTSB.

In the event of a crash of the vehicle the following procedure will be followed. Some these actions may have no benefit, as the vehicle may be unable to respond to remote radio commands after the crash.

- Initiate safety trigger to vent the vehicle tank.
- Manually initiate a hard abort to vent the vehicle tank.
- If the pressure status of the tank is unknown, no one will approach the vehicle.
- In the event that the tank cannot be remotely depressurized, with the above methods, the last resort may be to remotely puncture the tank (e.g. with a projectile)
- Once the tank pressure has been vented, local fire fighters will flood the area with water to dilute any spilled HTP.
- Wait for debris to cool.
- Drain any remaining HTP from the tank while continuing to flood the area with water.
- Clean up the debris and transport it to the service vehicle.

4. Environmental Impacts Analysis Information [§437.21(b)(1)]

The following propellants are used:

- 85% HTP (less than 150kg total per flight)

The following propulsion system pressurization gases are used:

- Gaseous Nitrogen

TrueZer0 expects the rest of the necessary environmental information to be provided by the LLC and will update this permit application once it is available.

5. Compliance with Additional Requirements

5.1 Information Requirements for Operations with Flight Crew and Space Flight Participants [§437.21(b)(3), Part 460]

N/A

5.1.1 Crew Qualifications and Training [§437.21(b)(3), §460.5 & §460.7]

N/A

5.1.2 Environmental Control and Life Support Systems [§437.21(b)(3), §460.11]

N/A: No humans on board the vehicle.

5.1.3 Smoke Detection and Fire Suppression [§437.21(b)(3), §460.13]

N/A: No humans on board the vehicle.

5.1.4 Human Factors [§437.21(b)(3), §460.15]

N/A

5.1.5 Verification Program [§437.21(b)(3), §460.17]

N/A

5.1.6 Spaceflight Participant Training [§437.21(b)(3), §460.51]

N/A

5.1.7 Security [§437.21(b)(3), §460.53]

N/A

5.2 Information Requirements for Obtaining a Maximum Probable Loss Determination for Permitted Activities [§437.21(b)(2); Appendix A to Part 440, Part 3]

TrueZer0 expects this information to be provided by the LLC and will update this permit application once it is available.

5.2.1 Identification of Location For Pre-Flight and Post-Flight Operations [Appendix A to Part 440, Part 3A]

TrueZer0 expects this information to be provided by the LLC and will update this permit application once it is available.

5.2.2 Identification of Facilities Adjacent to the Location of Pre-Flight and Post-Flight Operations [Appendix A to Part 440, Part 3B]

TrueZer0 expects this information to be provided by the LLC and will update this permit application once it is available.

5.2.3 Maximum Personnel Not Involved in Permitted Activities That May Be Exposed to Risk During Pre-Flight and Post-Flight Operations [Appendix A to Part 440, Part 3C]

TrueZer0 expects this information to be provided by the LLC and will update this permit application once it is available.

6. Vehicle Inspection [§437.21(d)]

The vehicle will be made available for inspection as soon as it is substantially complete. The date and time for the inspection is TBD.

7. Acronyms

CAN:	Controller Area Network
ERC:	Emergency Response Coordinator
ERT:	Emergency Response Team
GFO:	Ground Flight Operator
GPS:	Global Positioning System
HAFB:	Holloman Air Force Base
HTP:	High Test Peroxide
IIP:	Instantaneous Impact Point
IMU:	Inertial Measurement Unit
LLC:	Lunar Lander Challenge
MEMS:	Microelectromechanical Systems
MEOP:	Maximum Expected Operating Pressure
MSU:	Measurement and Status Unit
NTSB	National Transportation Safety Board
PSU:	Power Systems Unit
RTDV:	Rapid Tank Depressurization Valve
STO:	Safety Trigger Operator
XPF:	X Prize Foundation

Appendix A - Hazard Analysis

** S - Severity, L - Likelihood, R- Risk

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
1A	Avionics & Guidance	Loss of vehicle's flight computer/ navigation systems due to excessive environments or loss of data from one of the following components: GPS, gyro, accelerometer, altitude sensor, antenna, or telemetry system.	The consequence is possible death or serious injury to the public.	I	C	4	- Abort procedures for the ground crew. - Incorporate a redundant safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- Abort system commanded range verification for both the flight control, and redundant safety radios. - Preflight examination of safety systems. - The STO will be contacted to make sure they are in place, and ready to abort before each vehicle liftoff. - The vehicle's flight computer and navigation systems will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
1B	Avionics & Guidance	Loss of GPS signal due to hardware failure or excessive environmental conditions, resulting in erroneous data being uploaded to the vehicle's navigation system.	The consequence is possible death or serious injury to the public.	I	C	4	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- Abort system commanded range verification for both the flight control, and redundant safety radios. - Preflight examination of safety systems. - The STO will be contacted to make sure they are in place, and ready to abort before each vehicle liftoff. - GPS and associated hardware will be ground tested at expected (modeled) flight conditions. - GPS and associated hardware will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
1C	Avionics & Guidance	Failure of gyro due to hardware failure or excessive environmental conditions, resulting in erroneous data being uploaded to the vehicle's navigation system.	The consequence is a reduction in the capability of the vehicle's navigation system to function properly.	II	C	6	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered.	II	E	15	- Gyro and associated hardware will be ground tested at expected (modeled) flight conditions. - Gyro and associated hardware will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
1D	Avionics & Guidance	Failure of accelerometer due to hardware failure or excessive environmental conditions, resulting in erroneous data being uploaded to the vehicle's navigation system.	The consequence is a reduction in the capability of the vehicle's navigation system to function properly.	II	C	6	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered.	II	E	15	- Accelerometer and associated hardware will be ground tested at expected (modeled) flight conditions. - Accelerometer and associated hardware will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
1E	Avionics & Guidance	Failure of altitude sensor due to hardware failure or excessive environmental conditions, resulting in erroneous data being uploaded to the vehicle's navigation system.	The consequence is a reduction in the capability of the vehicle's navigation system to function properly.	II	C	6	- Redundant altitude sensors. - Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered.	II	E	15	- Altitude sensors and associated hardware will be ground tested at expected (modeled) flight conditions. - Altitude sensors and associated hardware will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
1F	Avionics & Guidance	Failure of antenna due to design inadequacies or excessive environments leads to loss of data. This results in erroneous data being uploaded to the vehicle's navigation system.	The consequence is a reduction in the capability of the vehicle's navigation system to function properly.	II	C	6	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered.	II	E	15	- Antenna and associated hardware will be ground tested at expected (modeled) flight conditions. - Antenna and associated hardware will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
1G	Avionics & Guidance	Loss of telemetry system due to hardware failure or software fault, resulting in erroneous data being uploaded to the vehicle's navigation system.	The consequence is a reduction in the capability of the vehicle's navigation system to function properly.	II	C	6	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered.	II	E	15	- Telemetry system and associated hardware will be ground tested at expected (modeled) flight conditions. - Telemetry system and associated hardware will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
1H	Avionics & Guidance	Loss of flight communication system due to hardware failure, which results in a reduction in the capability of Ground Command Station to communicate commands to the vehicle.	The consequence is a reduction in the capability of the vehicle's navigation system to function properly.	II	C	6	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered.	II	E	15	- Telemetry system and associated hardware will be ground tested at expected (modeled) flight conditions. - Telemetry system and associated hardware will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
1I	Avionics & Guidance	Incorrectly entered GPS coordinates or other guidance targets into flight computer.	The consequence is possible death or serious injury to the public.	I	C	4	ABORT procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually ABORT flight by cutting off the main engine. - Establish manned lookout(s) at the ABORT boundary. If the vehicle crosses the ABORT boundary, the safety abort is triggered. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	II	E	15	- Abort system commanded range verification for both the flight control, and redundant safety radios. - Preflight examination of safety systems. - The STO will be contacted to make sure they are in place, and ready to Abort before each vehicle liftoff. - See Appendix B for a description of our verification schedule.

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
2A	Flight Control Systems	Loss of flight control due to hardware failure or software fault, resulting in loss of control and crash of the vehicle.	The consequence is the possible death or serious injury to the public.	I	D	8	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- Flight control hardware will be ground tested at expected (modeled) flight conditions. - Flight control hardware will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
3A	Electrical System	Failure of any power source (i.e., battery) due to design inadequacies or excessive environments leading to safety-critical system loss and crash of the vehicle.	The consequence is the possible death or serious injury to the public.	I	C	4	- All battery voltages and currents are monitored before and during flight. If the any battery is showing excessive voltage drop, the ground crew will abort the flight. - Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - The safety abort system is powered by a battery which is completely separate from the flight control systems. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- All batteries will be ground tested at expected (modeled) flight conditions. - All batteries will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
3B	Electrical System	Electrical system short circuit resulting in loss of vehicle safety-critical systems and crash of the vehicle.	The consequence is the possible death or serious injury to the public.	I	D	8	- All battery voltages and currents are monitored before and during flight. If any battery is showing excessive voltage drop, the ground crew will abort the flight. - Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - The safety abort system is powered by a battery which is completely separate from the flight control systems. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- The vehicle's electrical system will be ground tested at expected (modeled) flight conditions. - The vehicle's electrical system will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
3C	Electrical System	Electrostatic discharge (ESD) during maintenance resulting in loss of components during flight and crash of the vehicle.	The consequence is the possible death or serious injury to the public.	I	E	12	N/A →→→ Risk is acceptable				
3D	Electrical System	Electromagnetic interference (EMI) causes failure of systems to operate in flight and crash of the vehicle.	The consequence is the possible death or serious injury to the public.	I	C	4	- Verify radio performance by communicating with vehicle before takeoff. - Implement soft abort system which will land the vehicle if contact is lost with the ground. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	2	D	10	- Telemetry system and associated hardware will be ground tested at expected (modeled) flight conditions. - Telemetry system and associated hardware will be tested according to our flight test plan (see section 2.1). - Soft abort system trigger conditions tested in simulator. - See Appendix B for a description of our verification schedule.

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
4A	Software and Computing Systems	Software or CPU malfunction which causes incorrect interpretation of navigation information, or incorrect control signals to be issued.	The consequence is the possible death or serious injury to the public.	I	D	8	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Establish manned lookout(s) at the abort boundary. If the vehicle crosses the abort boundary, the safety abort is triggered.	I	E	12	- Hardware and software will be ground tested at expected (modeled) flight conditions. - Hardware and software will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule. - Flight control software tested in simulator after each change.
5A	Structures	Structural failure due to design inadequacies or excessive environments resulting in a crash of the vehicle.	The consequence is the possible death or serious injury to the public.	I	D	8	- The main structure of the vehicle is designed to a safety factor of 1.5 or greater. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	1	E	12	- The primary structures will be tested according to our flight test plan (see section 2.1). - The following FAA/AST guidance document has been used to determine the appropriate verification safety factors for all structures: *Guide to Verifying Safety-Critical Structures for Reusable Launch and Reentry Vehicles*. - See Appendix B for a description of our verification schedule.
5B	Structures	Structural failure of the fuel tank due to design inadequacies or excessive environments resulting in a crash of the vehicle.	The consequence is the possible death or serious injury to the public.	I	C	4	- The tank is designed to a safety factor of 1.3 above MEOP. - A burst disk is used to protect the tank. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	1	E	12	- The fuel tank will be hydrostatically tested to 1.2 MEOP according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
6A	Thermal Protection system	N/A	N/A								

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
7A	Propulsion System	Thrust chamber failure due to design inadequacies resulting in a vehicle explosion.	The consequence is the possible death or serious injury to the public.	I	D	8	- Design rocket motor chamber to withstand a temperature of 910K. - Temperature of HTP decomposition products should not exceed 910K - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- The propulsion system will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
7B	Propulsion System	Inability to shutdown propulsion due to failure of the safety system.	The consequence is the possible death or serious injury to the public.	I	C	4	- Abort procedures for the ground crew. - The main engine can be can be cut off by commands from the flight control system or the safety system. - The likelihood of both systems failing simultaneously is remote since they are electrically and mechanically isolated. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- The safety system will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
7C	Propulsion System	Fuel leak from line rupture fitting failure, or valve failure leading to loss of vehicle thrust.	The consequence is the possible death or serious injury to the public.	I	D	8	- The entire fuel system has a safety factor of 2.0 or greater over MEOP. - Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	II	E	15	- The fuel lines will be hydrostatically tested to 1.2 MEOP according to our flight test plan (see section 2.1). - The following FAA/AST guidance document has been used to determine the appropriate verification safety factors for all structures: *Guide to Verifying Safety-Critical Structures for Reusable Launch and Reentry Vehicles*. - See Appendix B for a description of our verification schedule.

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
7D	Propulsion System	Over pressurization of fuel tank due to improper pressurization (design inadequacies, pressurization system failure) leading to tank bursting and loss of vehicle.	The consequence is the possible death or serious injury to the public.	I	D	8	- The tank has been designed to a safety factor of 1.3 over MEOP. - A burst disk is used to protect the tank. - Tank pressure is monitored by the flight control system at all times. - Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- The fuel tank will be hydrostatically tested to 1.2 MEOP according to our flight test plan (see section 2.1). - The following FAA/AST guidance document has been used to determine the appropriate verification safety factors for all structures: *Guide to Verifying Safety-Critical Structures for Reusable Launch and Reentry Vehicles*. - See Appendix B for a description of our verification schedule.
7E	Propulsion System	Loss of throttle control or XY gimbal control due to mechanical failure or loss of power causing the vehicle to crash.	The consequence is the possible death or serious injury to the public.	I	D	8	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- The propulsion system will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
7F	Propulsion System	Vehicle spins about its Z axis exceeding 150 degrees per second and the flight control system can no longer maintain stable vertical flight (attitude control system is inadequate)	The consequence is the possible death or serious injury to the public.	I	C	4	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- The propulsion system will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.

No.	System	Hazard Description	Results	**Risk Before Mitigation Measures			Risk Elimination or Mitigation Measures	**Risk After Mitigation Measures			Verification Evidence
				S	L	R		S	L	R	
8G	Propulsion System	Attitude control solenoid valve sticks open causing the vehicle to spin out of control and causing fuel tank depressurization resulting in a vehicle crash.	The consequence is the possible death or serious injury to the public.	I	D	8	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- The propulsion system will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
8H	Propulsion System	Attitude control system demand is greater than expected and excessive amounts of nitrogen are consumed. The vehicle can no longer generate adequate thrust and crashes.	The consequence is the possible death or serious injury to the public.	I	D	8	- Abort procedures for the ground crew. - Incorporate a redundant Safety system that allows the ground crew to manually abort flight by cutting off the main engine. - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- The propulsion system will be tested according to our flight test plan (see section 2.1). - See Appendix B for a description of our verification schedule.
9A	Landing System	Partial or full failure of legs leads to vehicle crashing.	The consequence Minor injury to the public or minor safety-critical damage	III	C	11	N/A →→→ Risk is acceptable				
9A	Vehicle Environmental Control	N/A	N/A								
10A	Natural Environments	The vehicle experiences wind gusts resulting in ground crew and the flight control system inability to control the vehicle. Probable crash of the vehicle inside the operating area.	The consequence is the possible death or serious injury to the public.	I	C	4	- Wind limits for launch permission. (maximum allowable wind speed to be determined during flight testing) - Uninvolved public will be kept outside the operating area during all hazardous pre-flight, flight, and post-flight operations.	I	E	12	- See Appendix C - Checklists and Flight Rules for a description of abort rules.
10B	Natural Environments	Natural or triggered lightning strikes the vehicle in flight leading to flight-safety system malfunction.	The consequence is the possible death or serious injury to the public.	II	C	6	- Monitor and report meteorological conditions to the mission conductor prior to launch. - Vehicle will not launch if lightning producing meteorological conditions exist.	II	E	15	- See Appendix C - Checklists and Flight Rules for a description of abort rules.

Appendix B - Verification Schedule

No.	System	Purpose	Test Description	Test Dates	Available Products for Delivery
1	Avionics & Guidance	To verify the operation of the flight computer/ navigation and telemetry systems under a range of conditions: - Due to excessive environments - Loss of data from the GPS, gyro, accelerometer, altitude sensor, antenna, or telemetry system	Ground testing: The IMU will be mounted in a moving vehicle (car), and data sets will be captured from all sensors over the course of a journey. These data sets will be analyzed for missing/incorrect data. Flight Testing: Flight computer/ navigation and telemetry systems will be integrated into the vehicle and flight tested according to the flight test plan outlined in section 2.1.	August 2008 (tentative)	- IMU data sets - Test logs - Videos of tests
2	Flight Control Systems	To verify the operation of flight control hardware and software.	Ground Testing: Each flight control hardware/software system will be independently tested as it is assembled. As the systems are integrated with the vehicle, they will be tested again. Flight Testing: Flight control systems will be integrated into vehicle and flight tested according to the flight test plan outlined in section 2.1.	August 2008 (tentative)	- Test logs - Videos of tests
3	Electrical System	To verify the operation of the electrical system under a range of conditions: - Due to excessive environments - Loss of system from short circuit, ESD, or EMI	Ground Testing: The electrical system will be integrated into the vehicle, and tested for short circuits, and other faults. During integration, and before each flight, processors will perform system self-tests and other diagnostics which should reveal failed electrical/electronic components. Flight Testing: The electrical system will be integrated into the vehicle and flight tested according to the flight test plan outlined in section 2.1.	August 2008 (tentative)	- Processor self-test logs - Test logs - Videos of tests
4	Software and Computing Systems	To verify software and computing systems are working as programmed.	Ground Testing: Firmware components will be tested individually to verify valid function before vehicle integration. The main flight computer is tested using a vehicle physics simulator which feeds simulated IMU data to the computer, and updates a simulated vehicle according to inputs from the flight computer. This will allow verification of the flight control algorithms in both normal and extraordinary conditions. During integration, and before each flight, processors will perform system self-tests which include checksum calculations over various firmware components to help ensure than no firmware corruption has taken place. Flight Testing: The software and computing systems will be integrated into the vehicle and flight tested according to the flight test plan outlined in section 2.1. Note: The flight control software will be re-tested in the simulator after each software change.	August 2008 (tentative)	- Processor self-test logs - Test logs - Videos of tests

No.	System	Purpose	Test Description	Test Dates	Available Products for Delivery
5	Structure	To verify the integrity of the structures of the vehicle under a range of conditions: - Due to excessive load environments - Due to design inadequacies	Ground Testing: The vehicle will be dropped from a height of 50mm to simulate a 1m/s impact. The vehicle should not make contact with the ground at speeds greater than this during normal operation (refer to section 2.1). Flight Testing: The integrity of the vehicle structure will be tested according to the flight test plan outlined in section 2.1.	August 2008 (tentative)	- Test logs - Videos of tests
6	Thermal Protection System	N/A	N/A		N/A
7	Propulsion System	To verify the integrity of the propulsion components (thrust chambers, fuel lines, tanks, valves, RTDV) of the vehicle under a range of conditions: - Due to excessive load environments - Due to design inadequacies	Ground Testing: The rocket motor and throttle valve with be tested and characterized on the motor test stand (refer to section 2.1). Flight Testing: The entire propulsion system including the safety system will be tested according to the flight test plan outlined in section 2.1.	June 16, 2008 June 28, 2008	- Test logs - Videos of tests
8	Landing System	To verify the operation of the legs	Ground Testing: The vehicle will be dropped from a height of 50mm to simulate a 1m/s impact. The vehicle should not make contact with the ground at speeds greater than this during normal operation (refer to section 2.1). Flight Testing: The capability of the legs to sustain actual landing loads will be tested according to the flight test plan outlined in section 2.1.	August 2008 (tentative)	- Test logs - Videos of tests
9	Vehicle Environmental Control	N/A	N/A		N/A
10	Natural Environments	To verify that the ground crew has been trained to the abort procedures described in our Flight Rules	Ground Testing: The entire abort process will be rehearsed with the vehicle fuel tank empty and depressurized. Flight Testing: The ground crew will practice its abort procedures according to the flight test plan outlined in section 2.1. NOTE: the complete safety system will never be tested in an untethered flight since this would result in a vehicle crash.	August 2008 (tentative)	- Abort process data set - Video of abort process test.

Appendix C - Checklists and Flight Rules

Staging Area Checklist			
No.	**Procedure**	**Criteria**	**Action**
1	Set flight parameters	- Confirm parameters from GPS	Go/No-Go
2	Check electrical systems	- Confirm electrical system status is good	Go/No-Go
3	Check mechanical systems	- Confirm mechanical system status is good	Go/No-Go

Pre-Flight Checklist [Sections G-4h & H-11a]				
No.	**Responsibility**	**Procedure**	**Criteria**	**Action**
1	Pad Operations	Power down vehicle	- Confirm electrical power to vehicle is "off"	Go/No-Go
2	Pad Operations	Visually inspect the entire vehicle	- Confirm no visible damage	Go/No-Go
3	Pad Operations	Verify main throttle valve position	- Confirm main throttle valve is closed	Go/No-Go
4	Pad Operations	Visually inspect vehicle's telemetry and safety radio antennas.	- Confirm no visible damage	Go/No-Go
5	Pad Operations	Clear operating area of uninvolved public	- Confirm zero population (uninvolved public) in operating area	Go/Hold
6	GFO	Ask event control for permission to fill HTP	- Confirm permission to fill	Go/No-Go
7	Pad Operations	Remove fuel cap and inspect	- Confirm cap is in good condition	Go/No-Go
8	Pad Operations	Close tank drain valve	- Confirm tank drain valve is closed	
9	Pad Operations	Verify operating area is clear of uninvolved public	- Confirm zero population (uninvolved public) in operating area	Go/Hold
10	Pad Operations	Fuel the vehicle	- Confirm 100L of 85% HTP is transferred to vehicle fuel tank	Go/No-Go
11	Pad Operations	Install fuel cap	- Confirm fuel cap is secure	Go/No-Go
12	Pad Operations & GFO	Power on entire vehicle and perform pre-flight self test	- Confirm vehicle batteries are charged - Confirm communications with the vehicle are working - Confirm no faults of any kind being reported by the vehicle's flight or safety systems.	Go/No-Go
13	Pad Operations	Connect remote tank pressurizing hose	- Confirm hose is securely connected to tank	Go/No-Go
14	GFO	Pad Operations personnel move at least 15 meters away from vehicle	- Confirm all Pad Operations personnel are at least 15 meters from vehicle	Go/Hold
15	GFO	Ask event control for permission to pressurize tank	- Confirm permission to pressurize	Go/No-Go
16	Pad Operations	Verify operating area is clear of uninvolved public	- Confirm zero population (uninvolved public) in operating area	Go/Hold
17	Pad Operations & GFO	Pressurize the fuel tank	- Confirm fuel tank pressure reaches operating pressure	Go/No-Go

18	Pad Operations & GFO	Remotely disconnect pressurizing hose	- Confirm hose is disconnected and retracted - Confirm tank is maintaining operating pressure	Go/No-Go
19	GFO	Pad Operations personnel join GFO in service vehicle and move approximately 100 meters from both pads A and B (see Figure 13).	- Confirm Pad Operations personnel are in the vehicle - Confirm vehicle is in position	Go/Hold
20	GFO	STO moves into position near service vehicle	- Confirm STO is in position (visually)	Go/Hold
21	GFO	Ask STO for status	- Confirm STO reports in position and ready	Go/Hold
22	STO	Verify operating area is clear of uninvolved public	- Confirm zero population (uninvolved public) in operating area	Go/Hold
23	GFO	Verify meteorological conditions	- Confirm sustained winds are below 5m/s (11.2 miles/hour) - Confirm wind gusts are below 7m/s (15.6 miles/hour) - Confirm visibility is greater than 2km (1.24 miles) - Confirm ambient temperature is between 5ºC and 40ºC (41ºF and 104ºF) - Confirm no rain, hail, or lightning producing storms in the area	Go/No-Go
24	GFO	Obtain permission to launch from event control	- Confirm permission to launch	Go/No-Go
25	GFO	Begin launch countdown and command launch	- Confirm vehicle reports no faults	Go/No-Go
No Go: 1. Depressurize tank by initiating safety system trigger 2. Verify tank pressure at atmosphere 3. Attach drain hose to tank drain valve 4. Open drain valve and flood area with running water (4 L/s minimum) to dilute HTP as it drains from the tank				
Hold: Wait for criteria to be met				

Safety Related Launch Commit Criteria	
No.	**Criteria**
1	Uninvolved public are outside the operating area
2	Vehicle passes visual inspection
3	Vehicle reports no faults
4	Meteorological conditions are met

Flight Rules [Sections G-4h & H-11b (i & ii)]		
No.	Scenario	Action
1	If main throttle will not open (thrust cannot be produced)	Initiate safety system trigger (see Appendix G - Aborts)
2	If the vehicle strays outside of the abort boundary (see Figure 12: Abort Boundary Detail)	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
3	If the vehicle loses telemetry link with the ground, and does not begin automatic soft abort	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
4	If a malfunction is detected in the vehicle's gyros or accelerometers	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
5	If a malfunction is detected in the vehicle's flight control hardware or software	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
6	If the vehicle's safety system battery voltage (14.8V nominal) shows a drop of more than 2.0V	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
7	If the vehicle power electronics battery voltage (22.2V nominal) shows a drop of more than 6.0V	Land vehicle immediately
8	If the vehicle flight computer battery voltage (11.1V nominal) shows a drop of more than 2.0V	Land vehicle immediately
9	If any software or CPU malfunction is detected	Initiate safety system trigger (see Appendix G - Aborts)
10	If the MSU ever detects a missing or malformed safety system heartbeat, it will alert the flight computer and a message will be sent to the GFO	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
11	If the flight computer ever loses communication with the MSU, PSU, or IMU for more than 5 seconds	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
12	If the flight computer detects a fault with the MSU, PSU, or IMU	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
13	If vehicle’s velocity exceeds 10m/s	Initiate safety system trigger (see Appendix G - Aborts) Initiate hard abort (see Appendix G - Aborts)
Abort Procedures: 1. Issue telemetry command to close main throttle, push gimbal to one extreme, and open attitude thrust solenoids 2. Issue safety system command to depressurize fuel tank		
Abort boundary: The boundary is defined in part by two 20m diameter cylinders. The first cylinder is centered on pad A and the second cylinder is centered one pad B. The boundary is further defined by two parallel planar walls tangent with the cylinders. The top of the boundary is defined by a horizontal plane 70m above the ground. See Figure 12: Abort Boundary Detail		

Post-Flight Checklist			
No.	**Responsibility**	**Procedure**	**Criteria**
1	GFO	Command vehicle to expend remaining propellant	- Confirm Thrust is below 400N
2	GFO	Monitor tank pressure	- Confirm tank pressure is atmospheric
3	GFO	Announce vehicle is safe to approach	- N/A
4	Pad Operations & GFO	Command throttle valve to open completely	- Visually verify throttle valve is open
5	Pad Operations	Remove the tank cap	- N/A
6	Pad Operations	Power down safety system	- Verify vehicle initiates hard abort (closes throttle and moves gimbal to minimum X-Y position)
7	Pad Operations & GFO	Power down vehicle power systems	- Verify telemetry indicates power system battery failure
8	Pad Operations & GFO	Power down flight computer	- Verify that telemetry stops

Appendix D - Fueling Procedure

Personal Safety:

1. Plastic Suit
2. Boots
3. Goggles
4. Rubber Gloves
5. Ear Plugs
6. Hose connected to pressurized water source
7. Fire extinguisher
8. Barricade

Fueling Procedure:

1. Remove Fuel Cap
2. Verify throttle valve is closed
3. Verify drain valve is closed
4. Place clean funnel into tank pour spout
5. Remove cap from jerry can and place in distilled water bucket
6. Pour HTP into tank through funnel (empty entire contents of pre-measured jerry cans)
7. Replace cap on jerry can
8. Repeat 5 through 7 until tank is filled to desired level
9. Tap excess HTP from funnel into tank
10. Place used funnel in distilled water bucket
11. Leave fuel cap removed (vented) until system is ready to be pressurized

Appendix E - Vehicle Parameters

FUEL	***Mass***	***Weight***	***Weight***
Item	(kg)	(N)	(lbs)
85% HTP	135.0	1324.4	297.7

PAYLOAD	***Mass***	***Weight***	***Weight***
Item	(kg)	(N)	(lbs)
Telemetry	5.0	49.1	11.0
Camera	5.0	49.1	11.0
Inert Weight	15.0	147.2	33.1
Total:	**25.0**	**245.3**	**55.1**

CRAFT	***Mass***	***Weight***	***Weight***
Item	(kg)	(N)	(lbs)
X Actuator	1.0	9.8	2.2
Y Actuator	1.0	9.8	2.2
Z Actuator	1.0	9.8	2.2
Tank	28.0	274.7	61.8
Rocket Motor	8.0	78.5	17.6
Throttle Valve	2.0	19.6	4.4
Z-Spin Nozzle	1.0	9.8	2.2
Z-Spin Valves	2.0	19.6	4.4
Frame	12.0	117.7	26.5
Shocks (4@0.25 kg)	1.0	9.8	2.2
Plumbing	5.0	49.1	11.0
Batteries	0.6	5.9	1.3
Electronics	2.0	19.6	4.4
Total:	**64.6**	**633.7**	**142.5**

Wet Total:	**224.6**	**2203**	**495**
Dry Total:	**89.6**	**879**	**198**

Appendix F - Minimum Operating Area Calculation

Vehicle thrust can be terminated through a hard abort or a safety system abort. Once the hard abort command is issued, the throttle valve will close relatively quickly (about 0.5 seconds). Thrust takes the most time to terminate if the hard abort mechanism fails, leaving only the safety system. The safety system abort depressurizes the tank to terminate thrust, so the thrust tails off according to Figure 5 (see section 1.2.1.3) over about 2 seconds. Given this, the calculation for the minimum operating area is based only on the safety system abort.

The minimum operating area calculation is done in two stages: Stage 1 (Pre-Abort) and Stage 2 (Thrust Tail-Off). Stage 1 determines the worst case position, velocity, and altitude that the vehicle can achieve before an abort is triggered. Once the abort is triggered, Stage 2 accounts for the thrust tail-off and determines the additional worst case position, velocity, and altitude that can be achieved from this tail-off. Once the tank is completely depressurized and thrust is terminated, the vehicle begins its free-fall descent. The resulting Instantaneous Impact Point (IIP) is used to define the minimum operating area.

The minimum operating area has been calculated at maximum and minimum ullage conditions. The maximum ullage condition requires the largest minimum operating area and is detailed below.

The equations of motion, Newton's second law, and the dimensions of the abort boundary specified in Figure 12 are used to perform the following calculations.

Stage 1:

The starting conditions are x_1 = 35m, z_1 = 70m (worst case edge of the abort boundary), and v_1 = 10m/s (maximum abort velocity). The tank pressure at maximum ullage is p_t = 1.72MPa. The maximum thrust that the motor can generate at this pressure is F_1 = 1881N (see Figure 10: Actual Motor Performance). The vehicle accelerates under this thrust during this stage until the safety system abort is triggered. The abort trigger time (reaction time) is t_r = 2.43s (maximum allowable to stay within the LLC operating area). Once the abort is triggered, the vehicle's free fall IIP is calculated. The conditions that yield the largest IIP distance are used as the input to Stage 2. As seen in the table below, a thrust angle of ϕ_1 = 48 degrees (measured from horizontal) is found to yield the worst case conditions.

Stage 2:

It takes t_{to} = 2.0s for the tank to depressurize during a safety system abort (see Figure 5: Thrust Tail-Off). The average tail-off thrust over that time period is F_2 = 594N. This average thrust is used to determine the vehicle acceleration until the tank is completely depressurized and thrust is terminated. Once thrust is terminated, the vehicle's free fall IIP is calculated. The conditions that yield the largest IIP distance are used to define the minimum operating area. As seen in the table below, a thrust angle of ϕ_2 = 47 degrees is found to yield the worst case conditions. The IIP at this thrust angle is X_{IIP} = 498.49m and defines the minimum operating area radius of 500m.

Operating Area Calculation: Stage 1

Maximum Ullage

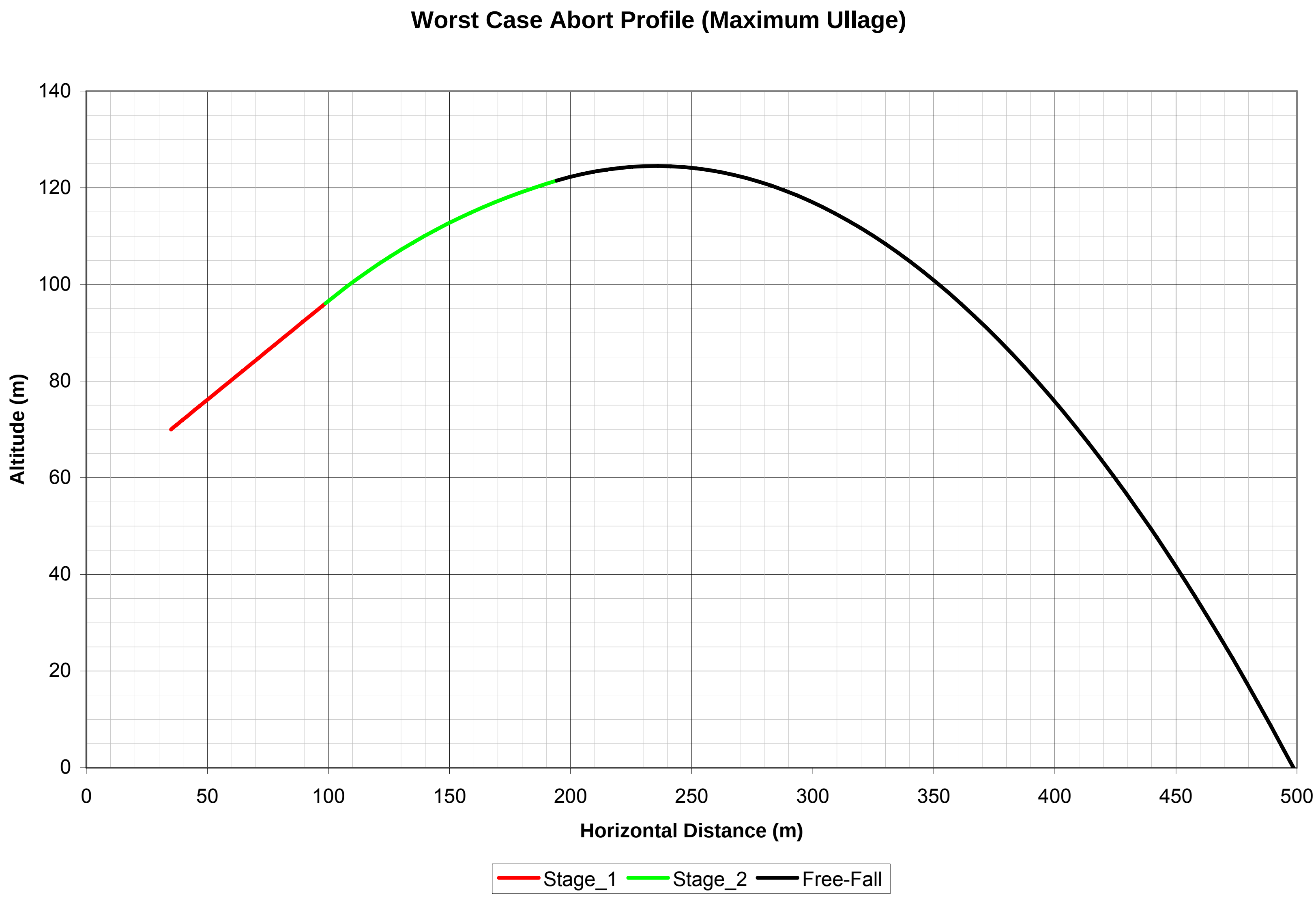
Slope: 1.28E-03
Intercept: -321

Thrust Vector Angle ϕ_1	Abort Cylinder Diameter D_{ac}	Abort Cylinder Distance X_{ac}	Vehicle Mass m_v	Tank Pressure p_t	Reaction Time t_r	Abort Altitude z_1	Abort Velocity v_1	Accel. Due to Gravity g	Horizontal Position x_1	Vehicle Thrust F_1	Accel. from Thrust $a_{t,1}$	Horizontal Accel. $a_{x,1}$	Vertical Accel. $a_{z,1}$	Accel. a_1	Time t_1	Horizontal Velocity $v_{x,1}$	Vertical Velocity $v_{z,1}$	Time Interval $t_2 - t_1$	Time t_2	Horizontal Velocity $v_{x,2}$	Vertical Velocity $v_{z,2}$	Horizontal Position x_2	Vertical Position z_2	Fall Time $t_{fall,2}$	Impact Time t^*_{IIP}	Impact Distance x^*_{IIP}
(deg)	(m)	(m)	(kg)	(Pa)	(s)	(m)	(m/s)	(m/s2)	(m)	(N)	(m/s2)	(m/s2)	(m/s2)	(m/s2)	(s)	(m/s)	(m/s)	(s)	(s)	(m/s)	(m/s)	(m)	(m)	(s)	(m)	(m)
1.0	20	50	90	1.72E+06	2.43	70.0	10.0													53.9						
30.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	18.1	0.6	18.1	0.55	9.99	0.35	2.43	2.98	54.0	1.9	112.7	72.7	4.0	7.03	331.26
31.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	17.9	1.0	17.9	0.56	9.99	0.53	2.43	2.99	53.5	2.8	112.1	74.1	4.2	7.18	336.22
32.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	17.7	1.3	17.8	0.56	9.97	0.71	2.43	2.99	53.0	3.8	111.6	75.5	4.3	7.32	341.01
33.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	17.5	1.6	17.6	0.57	9.96	0.89	2.43	3.00	52.5	4.7	110.9	76.8	4.5	7.46	345.61
34.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	17.3	1.9	17.4	0.57	9.94	1.08	2.43	3.00	52.0	5.6	110.3	78.1	4.6	7.61	350.02
35.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	17.1	2.2	17.3	0.58	9.92	1.26	2.43	3.01	51.5	6.5	109.6	79.5	4.7	7.76	354.22
36.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	16.9	2.5	17.1	0.59	9.89	1.45	2.43	3.02	51.0	7.5	109.0	80.8	4.9	7.90	358.19
37.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	16.7	2.8	16.9	0.59	9.87	1.63	2.43	3.02	50.4	8.4	108.2	82.1	5.0	8.05	361.91
38.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	16.5	3.1	16.7	0.60	9.83	1.82	2.43	3.03	49.8	9.2	107.5	83.5	5.2	8.20	365.38
39.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	16.2	3.3	16.6	0.60	9.79	2.01	2.43	3.03	49.3	10.1	106.7	84.8	5.3	8.35	368.59
40.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	16.0	3.6	16.4	0.61	9.75	2.21	2.43	3.04	48.7	11.0	106.0	86.1	5.5	8.50	371.51
41.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	15.8	3.9	16.2	0.62	9.71	2.40	2.43	3.05	48.0	11.9	105.2	87.3	5.6	8.65	374.13
42.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	15.5	4.2	16.1	0.62	9.66	2.59	2.43	3.05	47.4	12.7	104.3	88.6	5.7	8.79	376.45
43.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	15.3	4.4	15.9	0.63	9.60	2.79	2.43	3.06	46.7	13.6	103.5	89.9	5.9	8.94	378.45
44.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	15.0	4.7	15.8	0.63	9.54	2.99	2.43	3.06	46.1	14.4	102.6	91.2	6.0	9.09	380.12
45.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	14.8	5.0	15.6	0.64	9.48	3.19	2.43	3.07	45.4	15.3	101.7	92.4	6.2	9.24	381.45
46.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	14.5	5.2	15.4	0.65	9.41	3.38	2.43	3.08	44.7	16.1	100.7	93.6	6.3	9.38	382.42
47.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	14.3	5.5	15.3	0.66	9.34	3.58	2.43	3.09	44.0	16.9	99.8	94.9	6.4	9.53	383.04
48.0	**20**	**50**	**90**	**1.72E+06**	**2.43**	**70.0**	**10.0**	**-9.81**	**35**	**1881**	**20.9**	**14.0**	**5.7**	**15.1**	**0.66**	**9.26**	**3.79**	**2.43**	**3.09**	**43.2**	**17.7**	**98.8**	**96.1**	**6.6**	**9.67**	**383.29**
49.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	13.7	6.0	14.9	0.67	9.17	3.99	2.43	3.10	42.5	18.5	97.8	97.3	6.7	9.82	383.16
50.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	13.4	6.2	14.8	0.68	9.08	4.19	2.43	3.11	41.7	19.2	96.7	98.5	6.9	9.96	382.64
51.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	13.1	6.4	14.6	0.68	8.98	4.39	2.43	3.11	40.9	20.0	95.7	99.7	7.0	10.10	381.73
52.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	12.9	6.7	14.5	0.69	8.88	4.60	2.43	3.12	40.1	20.8	94.6	100.8	7.1	10.24	380.41
53.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	12.6	6.9	14.3	0.70	8.77	4.80	2.43	3.13	39.3	21.5	93.4	102.0	7.3	10.38	378.69
54.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	12.3	7.1	14.2	0.71	8.66	5.00	2.43	3.14	38.5	22.2	92.3	103.1	7.4	10.52	376.55
55.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	12.0	7.3	14.0	0.71	8.54	5.21	2.43	3.14	37.7	23.0	91.1	104.2	7.5	10.65	373.99
56.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	11.7	7.5	13.9	0.72	8.41	5.41	2.43	3.15	36.8	23.7	89.9	105.3	7.6	10.79	371.00
57.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	11.4	7.7	13.7	0.73	8.28	5.61	2.43	3.16	35.9	24.4	88.7	106.4	7.8	10.92	367.59
58.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	11.1	7.9	13.6	0.73	8.14	5.81	2.43	3.16	35.0	25.0	87.5	107.5	7.9	11.05	363.74
59.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	10.8	8.1	13.5	0.74	7.99	6.01	2.43	3.17	34.1	25.7	86.2	108.5	8.0	11.18	359.45
60.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	10.4	8.3	13.3	0.75	7.84	6.21	2.43	3.18	33.2	26.3	84.9	109.6	8.1	11.30	354.73
61.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	10.1	8.5	13.2	0.76	7.67	6.41	2.43	3.19	32.3	27.0	83.6	110.6	8.2	11.43	349.56
62.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	9.8	8.6	13.1	0.76	7.50	6.61	2.43	3.19	31.3	27.6	82.2	111.6	8.4	11.55	343.95
63.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	9.5	8.8	12.9	0.77	7.33	6.80	2.43	3.20	30.4	28.2	80.8	112.5	8.5	11.66	337.90
64.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	9.2	9.0	12.8	0.78	7.14	7.00	2.43	3.21	29.4	28.8	79.4	113.5	8.6	11.78	331.40
65.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	8.8	9.1	12.7	0.79	6.95	7.19	2.43	3.22	28.4	29.4	78.0	114.4	8.7	11.89	324.47
66.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	8.5	9.3	12.6	0.79	6.75	7.37	2.43	3.22	27.4	29.9	76.5	115.3	8.8	12.00	317.10
67.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	8.2	9.4	12.5	0.80	6.55	7.56	2.43	3.23	26.4	30.5	75.0	116.2	8.9	12.11	309.29
68.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	7.8	9.6	12.4	0.81	6.33	7.74	2.43	3.24	25.4	31.0	73.5	117.0	9.0	12.21	301.05
69.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	7.5	9.7	12.3	0.82	6.11	7.91	2.43	3.25	24.3	31.5	72.0	117.9	9.1	12.31	292.39
70.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	7.1	9.8	12.1	0.82	5.88	8.09	2.43	3.25	23.2	32.0	70.4	118.7	9.2	12.41	283.30
71.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	6.8	9.9	12.1	0.83	5.65	8.25	2.43	3.26	22.2	32.4	68.8	119.4	9.2	12.50	273.81
72.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	6.5	10.1	12.0	0.84	5.40	8.42	2.43	3.27	21.1	32.9	67.2	120.2	9.3	12.59	263.92
73.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	6.1	10.2	11.9	0.84	5.15	8.57	2.43	3.27	20.0	33.3	65.5	120.9	9.4	12.68	253.63
74.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	5.8	10.3	11.8	0.85	4.89	8.72	2.43	3.28	18.9	33.7	63.9	121.5	9.5	12.76	242.96
75.0	20	50	90	1.72E+06	2.43	70.0	10.0	-9.81	35	1881	20.9	5.4	10.4	11.7	0.85	4.62	8.87	2.43	3.28	17.8	34.1	62.2	122.2	9.6	12.84	231.93

Operating Area Calculation: Stage 2

Maximum Ullage

Thrust Vector Angle	Vehicle Mass	Tail-Off Time	Time	Distance	Altitude	Horizontal Velocity	Vertical Velocity	Accel. Due to Gravity	Average Tail-Off Thrust	Accel. from Thrust	Horizontal Accel.	Vertical Accel.	Time Interval	Time	Horizontal Velocity	Vertical Velocity	Horizontal Position	Vertical Position	Fall Time	Impact Time	Impact Distance
ϕ_2	m_v	t_{to}	t_2	x_2	z_2	$v_{x,2}$	$v_{z,2}$	g	F_2	$a_{t,2}$	$a_{x,2}$	$a_{z,2}$	$t_3 - t_2$	t_3	$v_{x,3}$	$v_{z,3}$	x_3	z_3	$t_{fall,3}$	t_{IIP}	x_{IIP}
(deg)	(kg)	(s)	(s)	(m)	(m)	(m/s)	(m/s)	(m/s2)	(N)	(m/s2)	(m/s2)	(m/s2)	(s)	(s)	(m/s)	(m/s)	(m)	(m)	(s)	(m)	(m)
1.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594												
30.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.7	-6.5	2.00	5.09	54.7	4.7	196.7	118.4	5.41	10.50	492.49
31.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.7	-6.4	2.00	5.09	54.5	4.9	196.6	118.6	5.44	10.53	493.17
32.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.6	-6.3	2.00	5.09	54.4	5.1	196.4	118.8	5.46	10.56	493.82
33.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.5	-6.2	2.00	5.09	54.3	5.3	196.3	119.0	5.49	10.58	494.43
34.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.5	-6.1	2.00	5.09	54.2	5.4	196.2	119.2	5.52	10.61	494.99
35.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.4	-6.0	2.00	5.09	54.0	5.6	196.0	119.4	5.54	10.63	495.52
36.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.3	-5.9	2.00	5.09	53.9	5.8	195.9	119.6	5.57	10.66	496.00
37.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.3	-5.8	2.00	5.09	53.8	6.0	195.8	119.8	5.59	10.68	496.45
38.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.2	-5.7	2.00	5.09	53.6	6.2	195.6	120.0	5.62	10.71	496.85
39.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.1	-5.7	2.00	5.09	53.5	6.4	195.5	120.1	5.64	10.73	497.20
40.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.1	-5.6	2.00	5.09	53.3	6.5	195.3	120.3	5.66	10.76	497.52
41.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	5.0	-5.5	2.00	5.09	53.2	6.7	195.2	120.5	5.69	10.78	497.79
42.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.9	-5.4	2.00	5.09	53.0	6.9	195.0	120.7	5.71	10.80	498.02
43.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.8	-5.3	2.00	5.09	52.9	7.1	194.9	120.8	5.74	10.83	498.20
44.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.7	-5.2	2.00	5.09	52.7	7.2	194.7	121.0	5.76	10.85	498.34
45.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.7	-5.1	2.00	5.09	52.6	7.4	194.6	121.2	5.78	10.87	498.43
46.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.6	-5.1	2.00	5.09	52.4	7.6	194.4	121.3	5.80	10.89	498.49
47.0	**90**	**2.00**	**3.09**	**98.8**	**96.1**	**43.2**	**17.7**	**-9.81**	**594**	**6.6**	**4.5**	**-5.0**	**2.00**	**5.09**	**52.2**	**7.7**	**194.2**	**121.5**	**5.82**	**10.92**	**498.49**
48.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.4	-4.9	2.00	5.09	52.1	7.9	194.1	121.6	5.85	10.94	498.45
49.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.3	-4.8	2.00	5.09	51.9	8.0	193.9	121.8	5.87	10.96	498.37
50.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.2	-4.8	2.00	5.09	51.7	8.2	193.7	121.9	5.89	10.98	498.24
51.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.2	-4.7	2.00	5.09	51.5	8.3	193.5	122.1	5.91	11.00	498.06
52.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.1	-4.6	2.00	5.09	51.4	8.5	193.4	122.2	5.93	11.02	497.84
53.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	4.0	-4.5	2.00	5.09	51.2	8.6	193.2	122.4	5.95	11.04	497.58
54.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.9	-4.5	2.00	5.09	51.0	8.7	193.0	122.5	5.97	11.06	497.27
55.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.8	-4.4	2.00	5.09	50.8	8.9	192.8	122.6	5.99	11.08	496.91
56.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.7	-4.3	2.00	5.09	50.6	9.0	192.6	122.8	6.00	11.10	496.51
57.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.6	-4.3	2.00	5.09	50.4	9.1	192.4	122.9	6.02	11.11	496.07
58.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.5	-4.2	2.00	5.09	50.2	9.3	192.2	123.0	6.04	11.13	495.58
59.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.4	-4.2	2.00	5.09	50.0	9.4	192.0	123.1	6.06	11.15	495.05
60.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.3	-4.1	2.00	5.09	49.8	9.5	191.8	123.3	6.07	11.17	494.47
61.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.2	-4.0	2.00	5.09	49.6	9.6	191.6	123.4	6.09	11.18	493.84
62.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.1	-4.0	2.00	5.09	49.4	9.7	191.4	123.5	6.10	11.20	493.18
63.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	3.0	-3.9	2.00	5.09	49.2	9.8	191.2	123.6	6.12	11.21	492.47
64.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.9	-3.9	2.00	5.09	49.0	9.9	191.0	123.7	6.13	11.23	491.72
65.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.8	-3.8	2.00	5.09	48.8	10.0	190.8	123.8	6.15	11.24	490.92
66.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.7	-3.8	2.00	5.09	48.6	10.1	190.6	123.9	6.16	11.25	490.08
67.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.6	-3.7	2.00	5.09	48.4	10.2	190.4	124.0	6.18	11.27	489.20
68.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.5	-3.7	2.00	5.09	48.2	10.3	190.2	124.1	6.19	11.28	488.28
69.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.4	-3.6	2.00	5.09	48.0	10.4	190.0	124.1	6.20	11.29	487.32
70.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.3	-3.6	2.00	5.09	47.7	10.5	189.8	124.2	6.21	11.30	486.31
71.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.1	-3.6	2.00	5.09	47.5	10.5	189.5	124.3	6.22	11.31	485.27
72.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	2.0	-3.5	2.00	5.09	47.3	10.6	189.3	124.4	6.23	11.32	484.19
73.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	1.9	-3.5	2.00	5.09	47.1	10.7	189.1	124.4	6.24	11.33	483.06
74.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	1.8	-3.5	2.00	5.09	46.9	10.7	188.9	124.5	6.25	11.34	481.90
75.0	90	2.00	3.09	98.8	96.1	43.2	17.7	-9.81	594	6.6	1.7	-3.4	2.00	5.09	46.6	10.8	188.7	124.6	6.26	11.35	480.71


Worst Case Abort Profile (Maximum Ullage)
Altitude (m)
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
Horizontal Distance (m)
Stage_1
Stage_2
Free-Fall

Appendix G - Aborts

In the event of failure, vehicle flights must sometimes be aborted.

TrueZer0 defines three methods for aborting a flight:

1) soft abort (always autonomous)
2) safety system trigger (always manual)
3) hard abort (autonomous, or manual)

Soft Abort:

Soft abort occurs when the vehicle flight computers have detected a non-critical fault which does not justify a crash landing of the vehicle, but which does justify ending the flight quickly.

The goal of the soft abort is to put the vehicle on the ground undamaged, and to shut it down quickly in situations where the GFO may not have the ability or reaction time to do so.

The following are the only conditions which will cause the flight computer to initiate an autonomous soft abort:

1) Loss of GPS signal or altitude data for more than 5 seconds.
2) Loss of communications with the ground control station.

During flight, the ground control station sends a ping signal once per second to the flight computer. If the flight computer notices that this signal is absent for more than 5 seconds, it considers communications with the ground control station to have been lost.

When a soft abort is triggered, the flight computer performs the following sequence:

1) Slows the vehicle's horizontal velocity to less than 1 m/s, stops vehicle ascent.
2) Starts vehicle descent (vertical velocity is limited to 10m/s during the descent, and is slowed as the vehicle approaches the ground).
3) Once contact with the ground is made (indicated by accelerometers on the vehicle), the motor is throttled off.

During a soft abort sequence, it is always possible to initiate a safety system trigger, or a hard abort.

Safety System Trigger:

The safety system trigger occurs only when the STO pushes the trigger button on the safety radio. This sends a signal to the safety system on-board the vehicle.

It is the STO's job to visually monitor the vehicle's flight. If the vehicle appears to significantly deviate from the flight profile or crosses the abort boundary, this individual would push the safety trigger button causing the vehicle thrust to terminate.

When the vehicle safety system is triggered, it performs the following sequence:

1) Activates the rapid tank depressurization mechanism.
2) Sends "triggered" status to the flight computer.

Hard Abort:

Hard abort occurs when a safety critical failure has been detected which justifies shutting down the vehicle immediately. If the vehicle is in flight when this happens, it will likely cause a crash and loss of the vehicle.

The following are the only conditions which will initiate a hard abort:

1) The GFO sends an abort command to the vehicle flight computer.
2) The flight computer determines that the vehicle has traveled across the abort boundary (see Figure 12 and Appendix F).
3) The flight computer determines that the vehicle has reached a velocity in excess of 10 m/s.
4) The flight computer detects that the vehicle safety system has been triggered.
5) The flight computer detects that the safety system battery voltage is 2.0V or more below nominal.
6) The flight computer detects a missing or malformed safety system heartbeat signal.
7) The flight computer loses communication with the MSU, PSU, or IMU for more than 5 seconds.
8) The flight computer detects a fault with the MSU, PSU, or IMU.

NOTE: during flight, the flight computer uses gyros and accelerometers along with GPS data, and barometric altitude data to determine the vehicle position and velocity. This information is updated at 100Hz. With each update, the position is compared with the abort boundary. If the position is determined to be outside of this boundary the flight computer will auto-initiate the hard abort procedure. Similarly, with each update the velocity is checked. If the velocity exceeds 10 m/s, the flight computer will auto-initiate the hard abort procedure.

NOTE: The safety system and flight computer are separate, electrically isolated systems. There is a one-way optical communications path from the safety system to the flight computer. This path is used to inform the flight computer of the safety system status. If the safety system is triggered by the STO, this status is sent to the flight computer. On receiving this status, the flight computer will initiate its hard abort procedure.

When a hard abort is initiated, the flight computer performs the following sequence:

1) Closes the throttle.
2) Opens the attitude thruster valves (to vent pressure from the fuel tank).
3) Pushes the gimbal mechanism all the way to one side to cause the vehicle to spin if the throttle remains open for any reason. This will assist in limiting the distance an out-of-control vehicle can travel.