Harding University Flying Bison 2009 USLI Rocket Team

Flight Readiness Review 2009

SUBMITTED BY

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Section I. Summary of FRR Report

1.1 Team Summary

1.1.a School Name: Harding University

1.1.b Location: 915 E. Market Ave.
Searcy, AR 72149

1.1.c Mentors: Edmond W. Wilson, Jr., Ph.D.
James E. Mackey, Ph.D.
David Stair

1.2 Launch Vehicle Summary

1.2.a Size: 3.9” ID, ~4.0” OD, 9.5’ Full Length

1.2.b Motor Choice: K-265 Contrail Rockets Hybrid, 54mm

1.2.c Recovery System: Drogue - 24” Classic II Sky Angle Parachute
Main - 60” Classic II Sky Angle Parachute
Standard Electric Match Ejection Charges

1.2.d Rail Size: 80/20 1 in square x 8 feet

1.3 Payload Summary

1.3.a Name: REMSPEC

1.3.b Purpose: To collect emission spectra from the exhaust plume of the hybrid rocket motor, in order to study the spectra *in situ* for changes in the burn profile due to airflow and forward motion.

1.3.c Input: Radiation from the hybrid motor exhaust plume

1.3.d Output: Analog signal in time proportional to intensity of the portion of the spectrum incident on the photodiode

1.3.e Components: Fiber optic cable for presentation of radiation to the diffraction grating
Diffraction grating for dispersion of the light source onto a mirror
Motor for positioning of the mirror to sweep entire spectrum across the photodiode detector
Photodiode detector for sampling spectrum as a time-based analog signal; will sample many spectra throughout the motor burn
Eagle Tree Systems Flight Data Recorder with Dual Channel A/D Input Board for acquisition and synchronization of spectra signals

Section II. Changes made since CDR

2.1 Changes made to Vehicle Criteria

2.1.a During construction of the rocket, the size of the fins were increased slightly to guarantee flight stability, under recommendation of the senior rocket hobbyist on the team .

2.2 Changes made to Payload Criteria

2.2.a No changes have been made to the Payload Criteria since the CDR.

2.3 Changes made to Activity Plan

2.3.a No changes have been made to the Activity Plan since the CDR.

Section III. Vehicle Criteria

3.1 Testing and Design of Vehicle

3.1.a Materials and Composition

To begin, all joints in the vehicle were bonded with industrial grade epoxy, the material of choice for high-powered rocket construction, with the exception of the motor retainer, which was fixed to the motor mount tube with JB Weld, per the recommendations of the manufacturer. Liberal amounts of epoxy were used whenever possible, to ensure bonding across all surfaces and edges.

The fins for the vehicle were purchased from Public Missiles Ltd., and are G-10 fiberglass material, precut by the manufacturer. The fins were sanded and shaped to reduce the span to 5", but the root chord was maintained at 9". The shape remains close to a standard delta design, but allows more surface area without introducing a larger profile, so as to mitigate concerns about the flight stability of the original fin design.

Bulkheads were constructed from 3/16" five-ply plywood, with an inner and outer bulkhead being wood glued together to allow for a sealed fit onto the coupler. This results in a section of the bulkhead that matches the coupler diameter that resides outside the coupler tube, and an adjoined bulkhead with diameter matching the inside of the coupler tube. Each coupler section is capped on both ends by such a bulkhead, and steel threaded rods run through the couplers and bolt onto the bulkheads to reinforce the couplers. Two ¼" steel threaded rods reinforce the upper coupler section, and three #10 steel threaded rods reinforce the lower coupler section. The difference results from a need to package the scientific payload effectively in the lower coupler section.

Centering rings are also composed of 3/16" five-ply plywood; special care was taken to affix the centering rings to the motor mount and the airframe with liberal amounts of epoxy.

The airframe itself is composed of Quantum Tubing, which is a light, strong polymer purchased from Public Missiles. Two rockets were built with this material prior to construction of the competition vehicle, and we are confident that the material is equal in strength to standard phenolic tubing, if not stronger.

The motor mount is composed of phenolic tubing. The retainer is composed of aluminum, and screws onto the end of the vehicle to ensure fail-safe motor retention.

The nose cone and boat tail are both composed of a particular white plastic used by Public Missiles.

The rail buttons are mounted to the rocket by wood screws that pass through the airframe and into the upper and lower centering rings. The wood screws have been tightened into place by hand, removed, and then replaced after filling the holes with liberal amounts of epoxy.

A test flight of the launch vehicle did occur on March 15th, with a subscale motor to keep the rocket beneath the ceiling of the Memphis NAR club. The motor used was a J-265SP, and the maximum altitude reached was 2047 feet. Below is the flight info and data from this test launch.

Recorded Max Acceleration:	346.53 f/sec/sec	Recorded Max Speed:	256.42 f/sec
Recorded Max Altitude:	1960 f		
Maximum Altitude (barometric):	2047.53 f	Maximum Altitude (integrated):	1808.11 f
Maximum Airspeed:	279.01 f/sec	Maximum Acceleration:	109.92 f/sec/sec
Maximum Mach:	0.25	Maximum Acceleration:	3.42 G
Altitude of Max. Airspeed:	698.71 f	Altitude of Max. Acceleration:	150.97 f
Time to Mach:	0 sec	Altitude of Mach Trans.:	0 f
Time to Apogee:	12 sec	Flight Length:	114.42 sec
Time to booster burnout:	4.21 sec	Time to 2nd Stage burnout:	0 sec
Altitude of Booster Burnout:	715.61 f	Altitude of 2nd Stage Burnout:	0 f
Descent Rate:	-21.65 f/sec		

This computer has been calibrated

3.1.b Assembly Quality

This vehicle has been constructed in the standard practice of high-powered hobby rocketry. A motor mount tube will contain the motor, and the motor will be given both forward and reverse retention by the motor retainer affixed to the protruding end of the motor mount tube. This retainer is affixed to the phenolic tubing with JB Weld to ensure a virtually fail-safe motor retention system.

The motor mount is attached to four centering rings and to the boat tail, which all make contact with the airframe at some point. These five joints are held by liberal amounts of industrial grade epoxy, and the lowest centering ring is also attached to the large end of the boat tail to discourage flexing or deformation of the plastic.

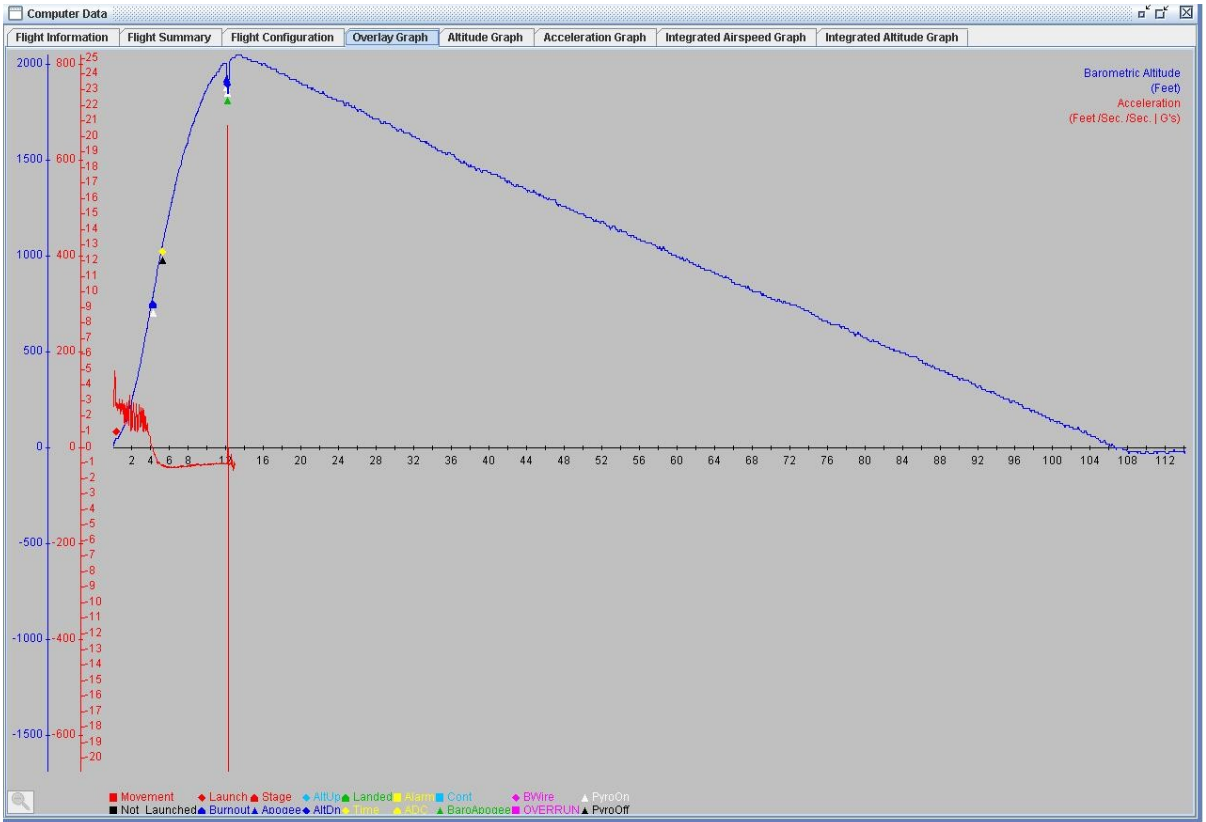

Figure 3.2: Test Flight Information

The boat tail and four centering rings serve two purposes: First, to center the motor mount inside the rocket, and second, to distribute the thrust of the motor up through the vehicle. The four centering rings alone are securely affixed to the inside of the polymer airframe with liberal amounts of epoxy, and on other types of rockets, would certainly be enough to distribute the load from the motor.

However, the boat tail provides an arched path to carry the load from the motor mount smoothly and seamlessly from the end of the motor mount up to the end of the airframe. The shoulders on the boat tail bear most of the load from the thrust, so that, even though liberal amount of epoxy are used on the joints, the cementing of these joints is not critical for load-bearing purposes.

It is important to mention that the fins are mounted to the motor mount tube through slots cut in the boat tail, in the classic “through-the-wall” design. This allows for a stronger connection to the vehicle by dividing whatever load is brought upon the fins between the 9” joint between the base of the fin tang and the motor mount, and the arced joint between the side of the fin and the boat tail surface.

The slots in the rocket body were measured with an ingenious method; by passing a standard laser pointer beam though a cylindrical lens, a vertical line resulted, and the slots were hand-cut with a Dremmel tool to match the dimensions of the fin. In this way, we are confident that no appreciable angling in the fins exists, and no post-launch spin with occur without wind influence.

After the load is distributed to the rocket body, the coupler tubes join the breaks in the airframe, and the load is simply carried up the rocket body to the nose cone. The couplers are held in place either by friction at separation point, or by three ¼” nylon bolts at points of non-separation.

When the recovery system is deployed, loads from the recovery harness are delivered to the I-bolts attached to the coupler sections. This load is then carried to the rocket body through the steel threaded rods bolted to each end of the couplers, onto the bulkheads. The nose cone is attached to the recovery harness with an I-bolt as well, that is attached to a bulkhead and cemented to the inner end of the nose cone.

3.1.c Workmanship

The question of workmanship is difficult to address in a written report, but great care has been taken to approach each step of construction deliberately and intelligently. The steps that are involved in constructing were all discussed with several team members before being undertaken, and the agenda of build steps was written out in detail to ensure no errors were made. All epoxy overflow from the joints was cleaned away, all exposed angle joints were filleted with a circular edge, and all surfaces were cleaned constantly with an abrasive pad.

In construction of this rocket, the prime concern was integrity, and so any surfaces bonded with epoxy were first sanded to ensure maximum bond strength. Holes and cuts were measured carefully to ensure proper load distribution. Coupler sections were sanded to the proper diameter to allow a good friction fit with the airframe sections.

3.2 Recovery Subsystem

3.2.a System Description

The requirements of the recovery system are to control the path and rate of descent of the launch vehicle after apogee so that the launch vehicle will pose no safety issue and will suffer no damage that would prevent an immediate reequip and launch.

The recovery system will employ black powder charges to separate the rocket at two points along the airframe, in order to release the drogue and main parachutes. Two redundant systems for igniting the charges will exist, both of which will be configured to fire distinct ejection charges at apogee and at an altitude of 800 feet, corresponding to deployment of the drogue and main parachutes, respectively. Nomex flame guards and flame-resistant wadding will be used liberally to prevent any burning or melting of parachutes or recovery harness.

A PerfectFlite MAWD flight computer and a G-Wiz LCX flight computer will serve as the cores for two completely redundant avionics subsystems. Both flight computers require a 9V operating voltage. The MAWD detects apogee with a barometric altimeter, which was likely the cause of the failure of last season. In order to prevent the barometer from

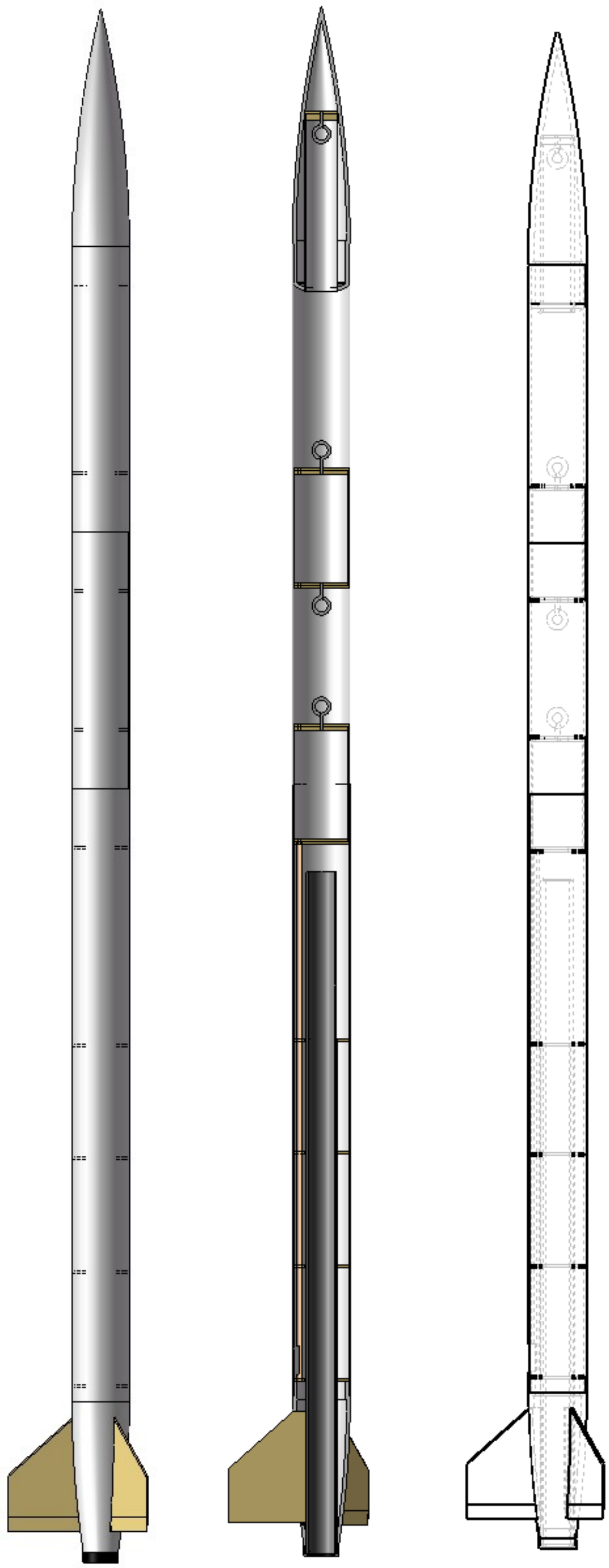

Figure 3.1: SolidWorks Renderings of the Launch Vehicle

detecting a premature apogee, the Mach timer feature will be employed to prevent the MAWD from firing any charges until after motor burn is completed (6.26 s). The LCX detects apogee with an accelerometer, which should not present the same risk as the MAWD. The MAWD audibly reports the peak altitude with a series of beeps after the flight is completed; this report will give the official peak altitude for the competition.

The ejection charges will be built using electric matches. FFFG black powder will provide the force necessary to separate the airframe. Ejection charges will be located so that the force of detonation will drive the shock cord and parachute out of the airframe, instead of into the airframe, to ensure quick deployment of the parachutes. Much of the recovery harness for the main parachute will be housed in the Public Missiles Intellicone, which has been cut and fitted with phenolic tubing. We have successfully deployed the recovery system from within the Intellicone, both on the ground and during the test flight.

The parachutes subsystem consists of the drogue parachute, the main parachute, and the shock cord employed by each. The drogue parachute will be a b3 Rocketry 24” Classic II Sky Angle parachute, which, given our current mass projections, will give the launch vehicle an approximate descent rate of 61 feet per second. The mass has been predicted to be approximately 14 pounds by entering specific masses for each component in RockSim, either from vendor specifications or from direct measurement when possible. 15 yards of 9/16” tubular nylon shock cord will secure this parachute to the avionics and scientific payload sections, and a Nomex flame guard will protect the parachute from the separation charge. The main parachute will be a b3 Rocketry 60” Classic II Sky Angle parachute, which will give the launch vehicle an approximate descent rate of 20 feet per second. 10 yards of 9/16” tubular nylon cord will secure this parachute to the interior of the nose cone and the avionics section, and a Nomex flame guard will protect this parachute as well.

Both the PerfectFlite MAWD and the G-Wiz LCX have been bench-tested and verified to be operational. They have also been verified on three rocket flights, including the test flight of the competition vehicle. The ejection charge sizes that have proven successful in ground and flight tests are 3 g of FFFG black powder for both the drogue and main parachute bays.

3.3 Mission Performance Predictions

3.3.a Mission Performance Criteria

- Performance of the launch vehicle in flight will be subject to these criteria:
- Vehicle reaches velocity for stable flight before leaving launch guide.
- Vehicle maintains stable flight throughout.
- Vehicle does not “weathercock” unreasonably.
- Vehicle reaches apogee at target altitude.
- Vehicle descends at 61 feet/sec under drogue.
- Vehicle descends at 20 feet/sec under main.

3.3.b Simulations

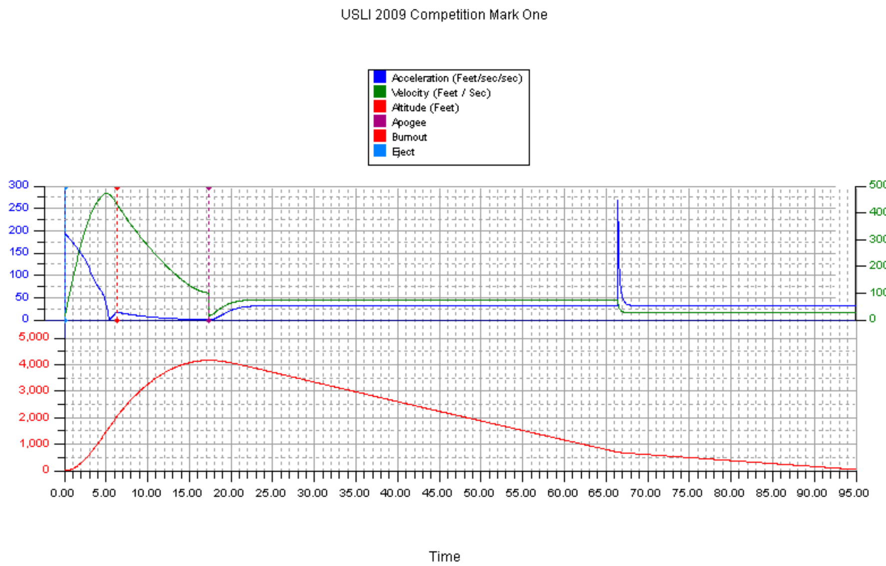

Figure 3.4: Plots of Simulated Flight Data.

These are the flight profile plots for a representative simulation in RockSim, with the first at apogee and the second at landing. All simulations were conducted with environmental conditions specific to Huntsville, Alabama, including average weather for the month of April.

After running six simulations under Huntsville conditions, the average peak altitude for the rocket was 4180 feet. This simulation was calculated from the actual weight of all completed rocket components; the rocket mass without the motor is 5810 grams. This

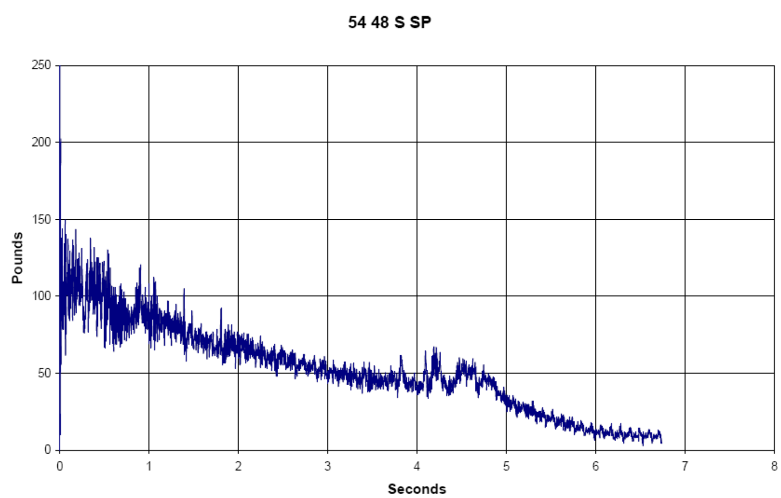

Figure 3.5: K-265SP Thrust Curve.

new simulatition has completely taken us by surprise, as we used the actual weight of pre-construction components for the simulation in the CDR. We are unable at this time to explain the apparent mass discrepancy, but work is being done to significantly reduce the rocket mass in hopes of regaining 1000 ft of altitude.

We are confident that an assessment of the rocket payload and various recovery connections can reduce the weight of the vehicle by at least one pound.

Figure 3.5 is the K-265SP motor thrust curve from certification testing provided to Contrail Rockets by Tripoli Rocket Association.

3.2.c Thoroughness and Validity of Analysis

The full specifications of the most accurate simulation of the launch vehicle, based on real component masses and weather conditions, are included below:

Engine selection [K265-None]

Simulation control parameters

3.2.d Stability

Flight resolution: 1000.000000 samples/second

Descent resolution: 500.000000 samples/second

Method: 4th Order runge-kuta.

End the simulation when the rocket reaches the ground.

Launch conditions

Altitude: 666.01050 Ft.

Relative humidity: 63.000 %

Temperature: 72.500 Deg. F

Pressure: 29.9139 In.

Wind speed model: Slightly breezy (8-14 MPH)

Low wind speed: 8.0000 MPH

High wind speed: 14.9000 MPH

Wind turbulence: Some variablility (0.04)

Frequency: 0.040000 rad/second

Wind starts at altitude: 0.00000 Ft.

Launch guide angle: 0.000 Deg.

Latitude: 34.700 Degrees

Launch guide data:

Launch guide length: 108.0000 In.

Velocity at launch guide departure: 53.5418 ft/s

The launch guide was cleared at : 0.335 Seconds

User specified minimum velocity for stable flight: 43.9993 ft/s

Minimum velocity for stable flight reached at: 73.2193 In.

Max data values:

Maximum acceleration:Vertical (y): 286.323 Ft./s/sHorizontal (x): 5.226 Ft./s/sMagnitude: 286.325 Ft./s/s

Maximum velocity:Vertical (y): 455.5853 ft/s, Horizontal (x): 17.4072 ft/s, Magnitude: 473.5495 ft/s

Maximum range from launch site: 1580.82125 Ft.

Maximum altitude: 4160.76146 Ft.

Recovery system data

P: Main Deployed at : 66.406 Seconds

Velocity at deployment: 72.1910 ft/s

Altitude at deployment: 699.98167 Ft.

Range at deployment: -939.98002 Ft.

P: Drogue Deployed at : 17.337 Seconds

Velocity at deployment: 101.2861 ft/s

Altitude at deployment: 4160.76146 Ft.

Range at deployment: -1580.82125 Ft.

Time data

Time to burnout: 6.260 Sec.

Time to apogee: 17.337 Sec.

Optimal ejection delay: 11.077 Sec.

Landing data

Successful landing

Time to landing: 97.020 Sec.

Range at landing: -494.37791

Velocity at landing: Vertical: -22.3787 ft/s , Horizontal: 17.4074 ft/s , Magnitude: 28.3518 ft/s

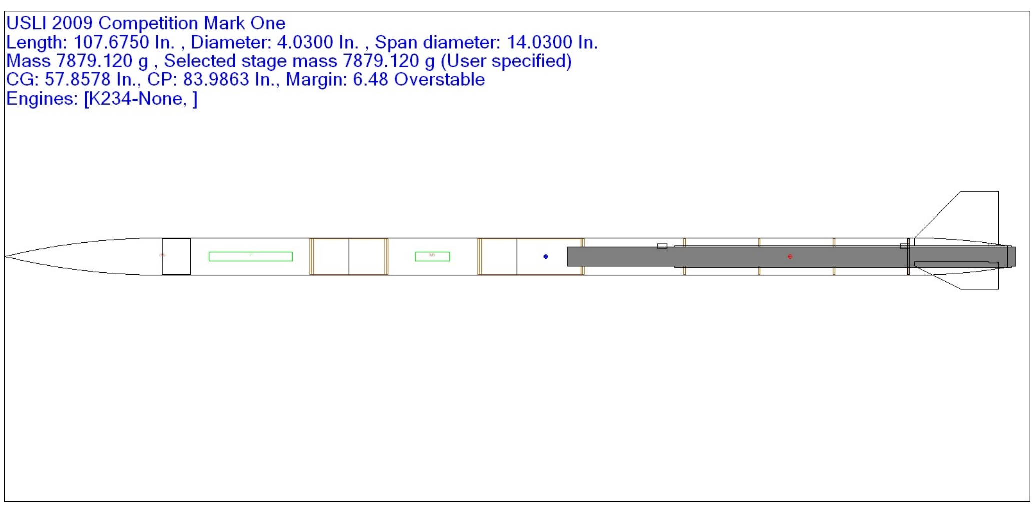

Figure 3.6: Competition Rocket Stability Diagram.

Observing the above drawing, the red dot shows the location of the center of pressure, and the blue dot shows the location of the center of mass. The center of pressure was calculated using the Barrowman stability equations. The simulated center of gravity is located at 57.86 inches from the nose of the rocket; the simulated center of pressure is located at 83.99 inches from the nose of the rocket. The resulting stability margin is 6.48 body diameters overstable.

With a user-specified stable-flight velocity of 44 ft/s, the rocket reaches the velocity for stable flight at 6 feet above the launch pad. Taking into account the location of the launch lugs, an eight-foot long launch guide should provide ample time for the rocket to accelerate into stable flight.

3.4 Safety and Environment (Vehicle)

3.4.a Safety Officer

The Safety Officer for the Harding University Flying Bison 2009 USLI Rocket team is Greg Lyons. Greg has been in the program for two years and is well equipped to fill this position. He will be responsible for monitoring all potentially hazardous activity throughout the project, and he will report to the Range Safety Officer during inspection and in the event of any safety concerns.

3.4.b Failure Analysis

Several failure cases of the propulsion system exist. A failure of the hybrid rocket motor subsystem would include three scenarios, and a failure of the support system would include one scenario.

The first scenario would be a catastrophic failure of the motor. The Harding University USLI team has been building hybrid rocket motors from Contrail Rockets for three years. We will observe and follow all procedure in constructing and launching our motor; a catastrophic failure is highly unlikely given proper construction procedure. Clearly, such a scenario would completely compromise the launch vehicle.

The second scenario would involve an incomplete fill of the nitrous oxide tank, which occurred the first season that Harding submitted a launch vehicle to the USLI competition. This scenario poses no risk to safety, assuming no other systems fail, but the rocket would not reach the target altitude. The possibility of this failure risks absolutely compromising the success of the mission. This scenario will be avoided by using binoculars to observe the vent line of the motor, and to only ignite the motor when nitrous has been venting for several seconds. The motor must be ignited immediately after the fill is turned off, so arrangements will be made with the Range Safety Officer to allow a shortened count-down (as was done last season).

The third and fourth scenarios both involve a failure to ignite, whether in the third case by a failure of the motor itself or in the fourth case by a failure of the support subsystem. Both scenarios will present the same characteristics, and in both, the Safety Officer will disconnect the ignition line from the support subsystem and report to the Range Safety Officer.

Several failure cases of the recovery system also exist. A failure of the avionics subsystem would involve two scenarios, and a failure of the parachutes subsystem would involve one scenario.

The first scenario would involve an early firing of an ejection charge during ascent. As was witness last season, such an event creates forces on the rocket that cannot be sustained, and the system would lose structural integrity and become a safety concern. In order to mitigate this risk, redundant avionics subsystems are employed, and the barometric altimeter flight computer (MAWD) will have ejection-charge firing locked out until after the motor burn is finished. The LCX flight computer detects apogee with an accelerometer, and will not fire if the rocket is still coasting upwards.

The second scenario would involve a failure of an ejection charge to separate and deploy a parachute. There are three cases: Failure to deploy drogue, failure to deploy main, and failure to deploy any. The first case would likely result in an extremely large impulse on the launch vehicle, and the recovery harness or the airframe would certainly lose integrity. This would result in subassembly component entering free-fall from 800 feet, which would be hazardous to all bystanders. The second case would result in a slowed descent of the vehicle to the ground, which would allow bystanders ample time to avoid, but the velocity of impact would likely damage components of the payload. The third case would result in a ballistic trajectory of the launch vehicle, which would be very hazardous to all bystanders and personnel. In order to mitigate these risks, the redundant avionics system has been employed, and thorough bench testing of both flight computers will occur.

The third scenario would involve a failure of a parachute to open due to tangling or some other circumstance. This scenario can usually be avoided by following the manufacturer's folding and packing instructions, and by leaving the interior of the parachute section free from anything the fabric or shock cord could catch on.

Failure of the scientific payload system or any of its subsystems during flight involves several unique failure cases. If the REMSPEC subsystem fails during flight, the scientific payload will fail absolutely. In order to minimize risk of this failure case, the REMSPEC will be thoroughly bench-tested in collecting spectra from real hybrid rockets fired on our rocket test stand.

If the data acquisition subsystem fails during flight, the scientific payload will fail absolutely. Once again, this subsystem will be bench-tested to minimize this risk, both against arbitrary analog signals and when interfaced with the REMSPEC.

If the telemetry subsystem fails during flight, the ability to receive spectra in real-time will be lost, but the spectra will be stored in the data acquisition subsystem's non-volatile memory, and will be recovered along with the launch vehicle. It should be noted that a failure of the telemetry subsystem would also affect the tracking system.

The recovery system has been deliberately designed to be completely independent of the scientific payload system. The electronics involved in the scientific payload play no role in the avionics subsystem; in fact, the two systems are physically separated by the drogue parachute chamber.

Failure of the tracking system or any of its subsystems during flight will result in loss of GPS data at the time of failure. Risks from failure include an inability to quickly locate the launch vehicle after flight; in order to minimize this risk, the recovery system has been designed to return the launch vehicle within 1000 feet of the launch site. It should be noted that a failure of the telemetry subsystem would also affect the scientific payload subsystem.

3.4.c Personnel Hazards

No hazardous chemicals are to be employed in this launch vehicle. The hybrid rocket motor components are completely inert until ignition, and are safe to handle in any situation until fully assembled and upright. The many legal and safety concerns associated with solid fuel ammonium perchlorate motors are not issues when using hybrid motors. Standard range safety procedure will be followed when igniting the rocket motor; this should prevent any danger to personnel and bystanders.

Care must be taken in the assembly of the ejection charges, as an accidental detonation could be hazardous. Hot gas and ejecta from a charge detonating in an unsealed airframe section would be harmful to personnel, so when ejection charges are being attached to the flight computers, all unnecessary personnel will be instructed to stand clear. When in transport, the leads of ejection charges will be twisted together, to prevent ignition by static discharge.

3.4.d Environmental Concerns

One of the reasons for current interest in hybrid rocket motors (and, incidentally, for our study of hybrid rocket motors) is the environmentally friendly products of a burn when compared to solid and liquid fuel motors. We are confident that the Contrail Rockets K-265SP motor will have a minimal impact on the surrounding environment. The major combustion products are carbon dioxide, water and heat. No waste material will be left at the launch site, assuming the rocket is reasonably intact and can be located. There is the danger of fire before liftoff. However, proper safety procedures greatly minimize the chance for a fire at launch.

3.5 Payload Integration

REMSPEC was designed to fit into a 3.75 in. i.d. by 11.50 in. long phenolic coupler tube. The coupler tube connects the aft section of the rocket containing the motor housing to the mid section of the rocket holding the drogue parachute. In construction of the airframe, a piece of 0.25 in. o.d. aluminum tubing was fed through small holes in the centering rings used to support and align the motor mount tube. A fiber optic cable was mounted on one of the fins. From there it entered the airframe and continued up through the aluminum guide/protection tube, through the aft coupler tube cover and into the REMSPECT spectrometer. The fiber optic cable was aimed at the mid section of the rocket exhaust plume on the end mounted on the fin and aimed at the entrance slit of REMSPECT on the other end. The cable collects the emission radiation from the exhaust plume and presents the radiation to the entrance slit of REMSPECT. REMSPEC with all of its subsystems can easily be detached from the airframe in one piece by removing six nylon bolts holding the coupler tube in place and sliding the

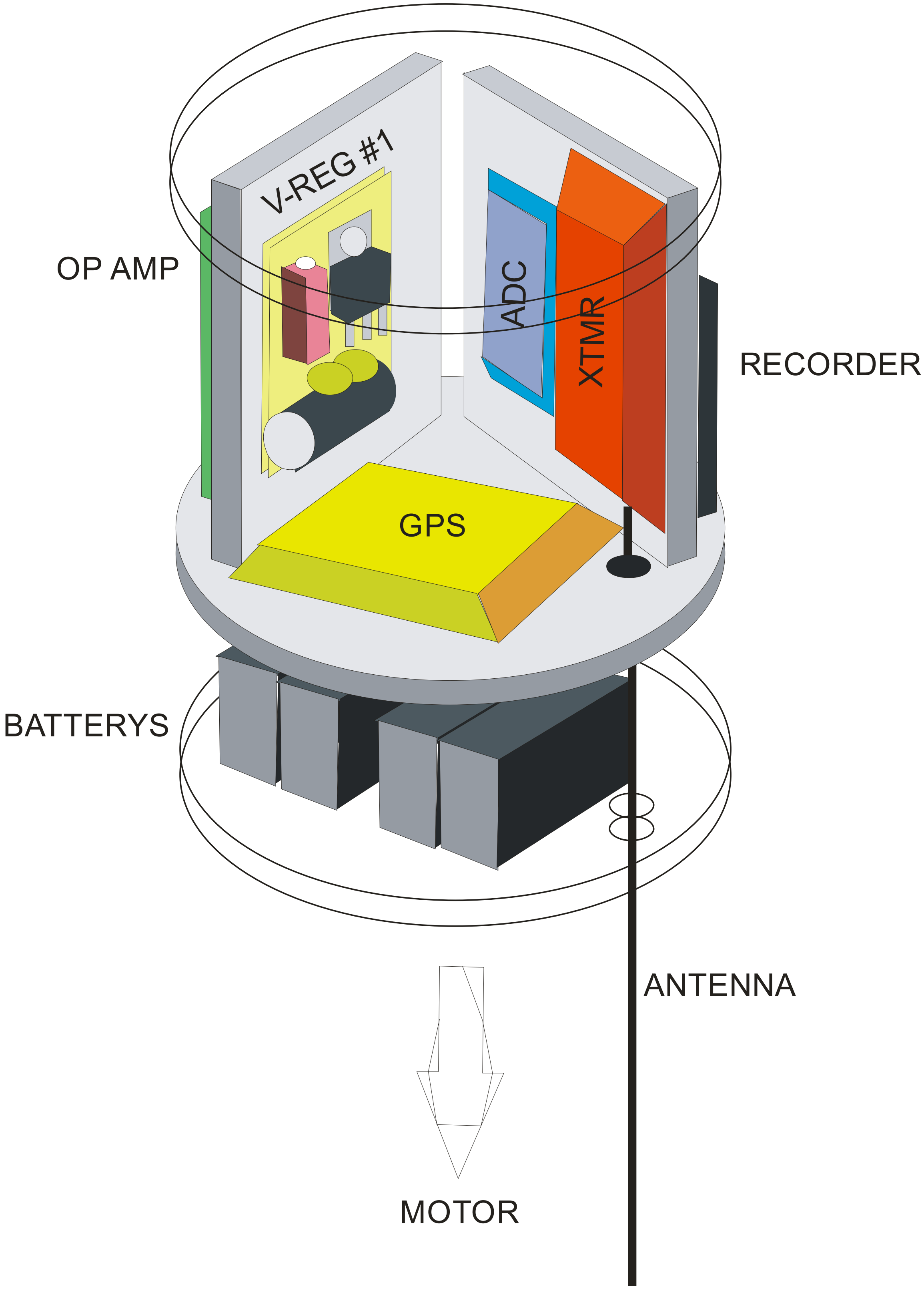

Figure 3.7 Schematic of REMSPEC

coupler tube out of the airframe for easy inspection, testing, repairing or replacing the 4 nine volt batteries.

The launch vehicle flew without the scientific payload and tracking systems during the first test flight in order to protect them in case of failure. This was easily accomplished because the REMSPECT science payload is completely contained in the aft coupler tube while the flight computers and sensors are completely contained in the forward coupler tube. Therefore empty coupler tubes were installed for the maiden flight.

Section IV Payload Criteria

4.1 Testing and Design of Payload Experiment

4.1.a.1 Review of design at system level

The Science Payload is a ***R***ocket ***EM***ission ***SPEC***trometer, **REMSPEC**, which will measure the emission spectrum of the exhaust plume of our hybrid rocket motor (See Figs. 4.1 and 4.2). A spectral range of 280 nm through 1000 nm will be measured at a rate of five times per second starting at ignition and continuing through burnout (approximately four seconds). It consists of the following subsystems:

Fiber optic cable light gathering subsystem – A jacketed 1 meter multimode fiber optic cable, transparent from 280nm through 1000nm with a light collecting lens on one end, is used to transmit the optical emission from the hybrid rocket motor exhaust plume to the spectrometer. Fig. 4.1 shows the cable mounted to the surface of one of the fins and aimed towards the middle of the exhaust plume. The fiber optic cable enters the airframe near the top of the fin and travels inside the airframe and through the bulkhead spacers that stabilize the motor shell. It enters the bottom of the REMSPEC instrument where it delivers the light from the exhaust plume to the entrance slit of the spectrometer. The complete instrument fits within the volume of an 11.5 inch long phenolic coupler used to connect the aft and middle sections of the airframe. See Fig. 4.2.

Monochromator subsystem – An ultraviolet-visible-near infrared monochromator covering the spectral range of 280 nm through 1000 nm recording spectra at a rate of 5 Hz with a spectral resolution of 1 nm has been designed and built (See Fig. 4.3). The detector was designed to give good response throughout the entire spectral range with a response time of 10 μs or better. The detector produces a microamp current proportional to the amount of radiation striking it. The plastic holographic transmission grating has 750 grooves per millimeter and was blazed to a 550 nm wavelength. It has a 23.5 dispersion angle. Mirrors fold the path of the light beam to reduce the amount of space needed by the instrument (See Figure 4.3).

Detector subsystem -- The detector should give a good response throughout the entire spectral range and exhibit a response time of 10 μs or better. The detector produces a current proportional to the amount of radiation striking it. A signal conditioning unit to convert the current from the detector into a voltage and amplify the voltage so that the minimum and maximum radiation intensities are scaled to a voltage between 0 and 4 volts to match the analog to digital converters has been designed and built. Fig. 4.4, 4.5 and 4.6 show initial test results of spectrometer.

Microcontroller subsystem -- is a commercial, off the shelf, (COTS) microcontroller with an on board GPS system and Pitot tube for altitude and airspeed. Fig 4.5 shows the exhaust plume in the upper left hand corner. The fiber optic cable gathers the light from the plume and directs it into the spectrometer. The diffraction grating spreads the light into a spectrum and sends it to the detector by means of the rotating mirror. The detector current is fed into a signal conditioning circuit which increases the impedance through a unity gain operational amplifier and then it is converted to a voltage by means of a resistor. Next, the voltage signal which contains the spectrum is amplified so that the largest signal is + 4 volts. This conditioned signal if fed into a 15 bit digital to analog converter and the digitized signal sent to storage on board the microcontroller and to the wireless transmitter where it is sent to a ground based computer that is recording, position, altitude, airspeed and the rocket exhaust spectrum in real time. This system is completely isolated from the flight computer and can act as a tertiary back up to record flight data should the primary flight computer and secondary back up computer fail. The whole system is very compact (fits in 11.5 in. section of coupler tube) and weighs 2.18 lb (989.8 g).

Power supply subsystem – The entire Science Payload operates on four 450 mlliamp hour, 9 volt batteries are used for the power supply.

4.1.a.2 Drawings and specifications

REMSPEC Science Payload

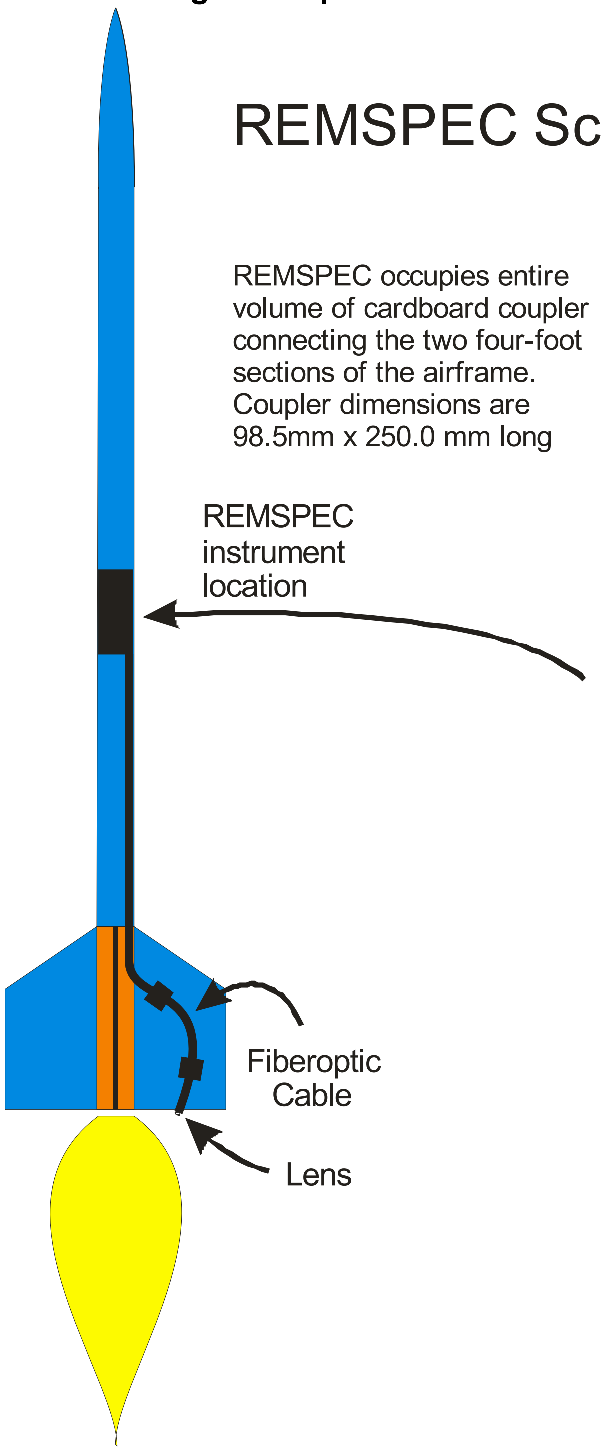

Figure 4.1 Schematic showing REMSPEC location and fiber optic cable placement.

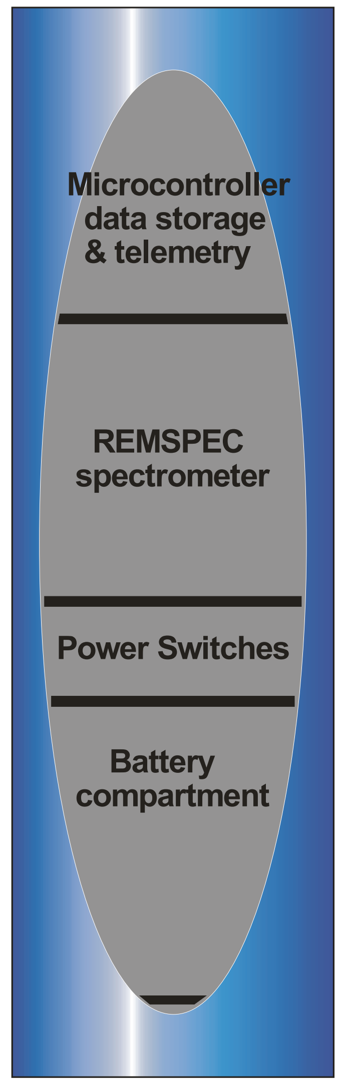

Figure 4.2 Schematic of coupler tube showing arrangement of sub systems.

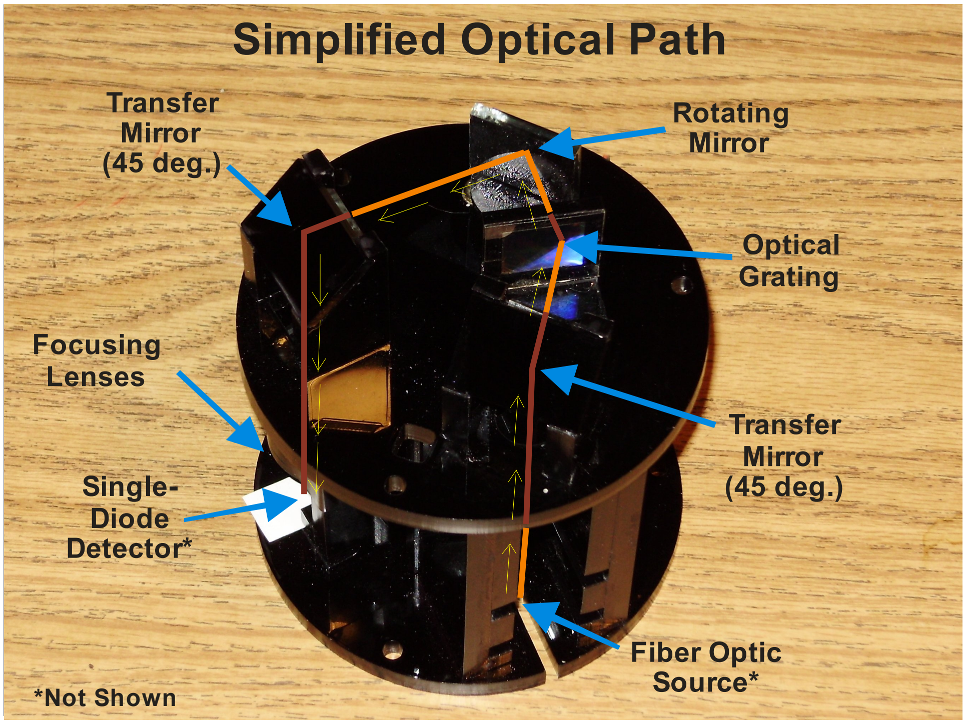

Figure 4.3. Photograph of spectrometer subsystem of REMSPEC. Light beam drawn in to illustrate path of light traveling through the spectrometer. The light beam is folded in order to maintain a large light path while economizing space.

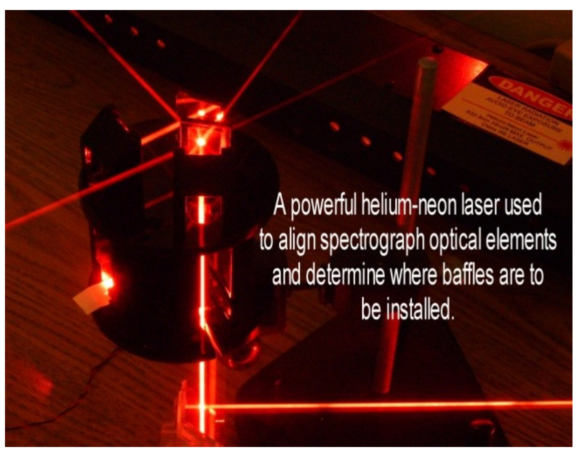

Figure 4.4. Helium-neon laser beam shining into entrance port of spectrometer. This was done to know where to install baffles to remove scattered light and also to check the mechanical alignment of the optics.

Figure 4.5 Spectrum of helium-neon laser showing one red spot at the exit focal plane as would be expected since this laser emits a single red wavelength, 632 nm.

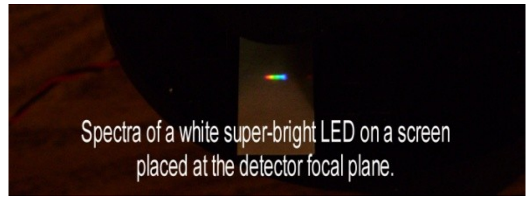

Figure 4.6 Spectrum of Super-Bright LED at the focal plane. The spectrum is clearly visible with red on the left and blue on the right.

Microcontroller Subsystem -- All of the subsystems are controlled and monitored by a SeaGull HP High Powered Rocketry Package. The microcontroller has the following additional subsystems:

- Wireless Telemetry Transmitter, 900 Mhz, 200 mW
- Dashboard Receiver
- Flight Data Recorder
- GPS Expander
- SMA Dashboard Antenna
- Pitot Tube (Will not be used)

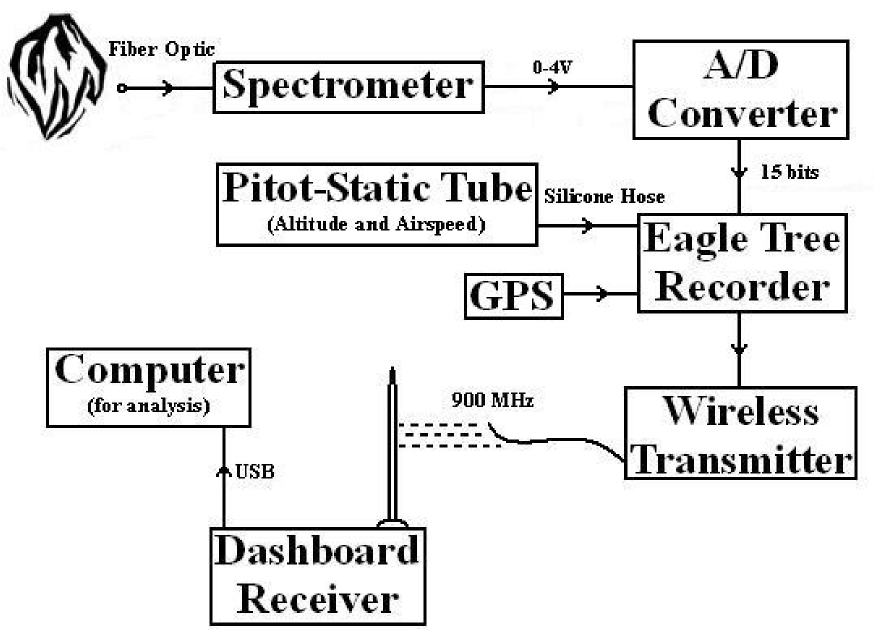

Figure 4.7 Schematic of microcontroller subsystem.

4.1.a.3 Analysis Results

The REMSPEC instrument will measure the spectra of the hybrid rocket exhaust plume five times per second for 6 seconds, giving 30 spectra.

4.1.a.4 Test Results

At the time of this FRR report, we have measured, with REMSPECT, the spectrum of a 640 nm diode laser beam, a calibrated hydrogen discharge lamp and a three color LED. Qualitatively, these all produced the expected spectra. However, we have not yet carried out exhaustive calibrations with a mercury vapor lamp which will give us an indication of the response of the system.

4.1.a.5 Integrity of Design

The system has been designed and built to be rugged and impervious to normal shock and shaking although we have not yet done any tests.
It is constructed of quarter inch cast acrylic plate and reinforced with three quarter inch all-thread rails. Because it is enclosed in a phenolic coupler tube and capped with half inch plywood secured with quarter inch bolts, nuts and lock washers, it should be robust as far as shock due to rocket launch and landing.

4.1.b Demonstrate that the design can meet all system level functional requirements

The planned precision of REMSPEC is 5% standard deviation in peak areas for chemical species found in the exhaust plume and ± 1 nm wavelength accuracy. The Science Payload is an integral part of the airframe and will use the same recovery procedures as the rocket itself. Data will be downloaded to a laptop computer once the rocket is recovered. As a redundancy, the data will also be sent during flight by telemetry to a computer on the ground. As of the writing of this FRR, the system has not been tested.

4.1.c Specify approach to workmanship as it relates to mission success.

The optical bench, chassis and batter compartment were constructed from quarter inch thick cast acrylic. The drawings of the parts were rendered in CorelDraw X3, converted to vector graphics. The vector graphics file was fed into a carbon dioxide laser cutting machine and each part was cut to size with an accuracy of ±0.004 in. The individual pieces were glued together with methylene chloride solvent as the glue.

The circuit boards were also drawn in CorelDraw X3. These drawings were used in the etching method to produce the circuit boards using standard copper clad boards as the substrate.

All mirrors and lenses were from commercially available off the shelf parts, COTS. All electronics components were standard commercially available components.

The entire instrument was mounted inside a 3.75 in. diameter by 11.5 in phenolic coupler tube from Contrail Rockets and stabilized with three 11.5 in. threaded steel all-thread rods at 120 degree intervals to which the instrument was secured. The ends of the coupler tube were capped with half inch plywood centering disks.

4.1.d Discuss planned component testing, functional testing, or static testing

The various components of the system, the battery power supply, the optical bench with rotating mirror and the Eagle Tree data collection and transmission system have each been tested separately. Further testing will be with the fully integrated system.

- REMSPEC will be turned on and operated with fresh 9 volt batteries and the amount of time till the batteries fail will be noted.
- REMSPEC will be used to measure the spectrum of a standard low-pressure mercury vapor lamp which gives well established peaks at known wavelengths throughout the spectral range to be measured. The instrument wavelength coverage will be estab-lished by preparing a calibration algorithm for data analysis using the known versus measured values of the mercury vapor spectrum.
- REMSPEC will be used to measure the exhaust plumes of Contrail Hybrid Rocket Motors mounted statically to Harding University Rocket Test Stand 1.

4.1.e Status and plans of remaining manufacturing and assembly

The unfinished items in manufacturing are some electronic boards that are being improved after initial testing in order to decrease noise and improve stability.

The battery compartment and the EagleTree computer system have to be assembled onto their acrylic mounting boards and wired.

The mirrors of REMSPEC are undergoing additional alignment positioning to improve signal to noise.

4.1.f Describe integration plan

REMSPEC will be integrated into the airframe by Paul Elliot, Leader for Rocket Design and Simulation with the aid of REMSPEC Leader Bush. Integration of the microcontroller subsystem with REMSPEC spectrometer will be done by Nathan Smeal and Jon Langford, Leaders for Electronics again with REMSPEC Leader Bush. Finally, integration of REMSPEC with the telemetry subsystem will be carried out by Nathan Smeal and Jon Langford (Electronics) with the aid of Bush (REMSPEC). We have not tested the instrument under flight conditions at the time of the FRR.

4.1.g Precision of instrumentation, repeatability of measurement

The designed precision of measurement was ±1 nm of wavelength reproducibility.
REMSPEC with gather 5 spectra per second and these should agree within ±1nm wavelength and ±5% of peak height.

4.1.h Safety and failure analysis

4.1.h.1 The Science Payload failure modes are:

Battery failure. Fresh batteries will be installed in the Science Payload just prior to launch. Testing will be done before launch day to determine the length of time the batteries will have enough power to keep the instrument working.

Failure to initiate operation of the spectrometer. Testing the spectrometer on the launch vehicle at least once before the competition is the only way to build confidence that REMSPEC will take data as planned.

Failure of the mirror to rotate during flight. Thrust bearings will be installed on the motor to minimize the frictional forces encountered during a flight. Again, testing with a launch will help to minimize failure during competition.

4.2 Payload Concept Features and Definition

4.2.a Creativity and originality

To our knowledge, no one has built a spectrometer specifically designed to operate during flight of a high powered rocket. The concept of a spinning mirror allows building the instrument without having to purchase an expensive photodiode linear array with its sophisticated electronics. This is a major factor when a malfunction and loss of the rocket is a distinct possibility. second goal is to use the above information during flight to provide a feedback loop to control (throttle) the rate of combustion. The third goal is the determine the impact of the firing on the environment (Green Chemistry).

4.2.b Uniqueness or significance

The uniqueness of REMSPEC is the rotating mirror that precludes the use of an expensive and more complex linear array detector instead of the single photodiode detector used. The significance is that this is a way of monitoring, in flight, the behavior of a rocket motor with the possibility of using the output signal as part of a feedback loop to actually control the thrust of the motor.

4.2.c Suitability level of challenge

In order to accomplish the tasks associated with the Science Payload, the team has to apply principles of spectroscopy, electronics, computer interfacing, including digital to analog conversions, and telemetry under very hostile conditions during the flight of a high powered rocket. This is a challenging project that is quite appropriate for college level juniors, seniors and beginning graduate students in chemistry, electrical and mechanical engineering.

4.3 Science Value

4.3.a Describe science payload objectives

The Science Payload Objectives are:

- Obtain 30 measurements of the emission spectrum of rocket exhaust plume beginning with rocket motor ignition and repeating at a frequency of 5 times per second for a total of 6 seconds. The measurement will include the spectral range of 280 nm in the ultraviolet through 1000 nm in the near-infrared.
- Transmit the recorded emission spectra data wirelessly to a ground monitoring center during rocket flight.

- Identify chemical signatures in the rocket exhaust plume and graph the amount of each substance present as a function of time during the rocket burn.

4.3.b State the payload success criteria

The Payload Success Criteria is a successful flight returning at least three useable spectra stored in the onboard memory of the science payload.

4.3.c Describe the experimental logic, approach and method of investigation

It makes sense to monitor the behavior of any motor to allow for anticipating failure, improving performance and registering environmental pollution. The approach is to apply the principles of spectroscopy to a challenging problem: monitor the exhaust plume of a rocket motor during flight. The method of investigation will be to digitize the output of REMSPEC, store the data with timeing, and then interpret the resulting spectra with known spectra taken in the laboratory.

4.3.d Describe the test and measurement, variables and controls

Test measurement variables include the speed of the rotating mirror, the rate of conversion of the photodiode detector and analog to digital converter, rate of data storage and storage capacity of the computer memory. Also, the voltage produced by the photodiode detector is variable. All these variables will be tested multiple times before the FRR.

4.3.e Show relevance of expected data, accuracy, error analysis

Optimal data collection would produce results that equal those of the commercial spectrometer which include 1 percent repeatability of the instrument under controlled laboratory conditions for both peak areas and wavelengths of the spectra. Plans are developed for full testing of the REMSPEC simultaneously with a commercial spectrometer both in the laboratory and using the Harding University Hybrid Rocket Test Stand 1 firing hybrid rocket fuel grains using nitrous oxide as the oxidizer.

4.3.f Describe the experimental process procedures

Science Payload Leader Megan Bush has carried out two test stand burns of a smaller hybrid rocket motor using nitrous oxide fuel. A commercial spectrometer was used to establish baseline spectra. The REMSPEC prototype has been completed and is now in the laboratory testing phase. A low pressure mercury vapor lamp will be used to produce spectra that are in industry standard for spectrometer testing in the wavelength range of REMSPEC. From this test, many of the accuracy metrics will be establish placing a limit on the accuracy and reproducibility of REMSPEC.

4.4..Experiment Design of Payload

4.5 Assembly

4.4 Safety and Enviromental (Payload)

4.4.a Identify Safety Officer for your team

The Safety Officer for the Harding University Flying Bison 2009 USLI Rocket team is Greg Lyons. Greg has been in the program for two years and is well equipped to fill this position.

4.4.b Update the preliminary analysis of the failure modes of the proposed design of the rocket, payload integration and launch operations, including proposed and completed mitigations

No additional failure modes have been noticed during the field trials of the rocket.

4.4.c Update the listing of personnel hazards, and data demonstrating that Safety Hazards have been researched (Such as Material and Safety Data Sheets, operators manuals, NAR regulations), and that hazard mitigations have been addressed and mitigated.

No chemicals are used in the Science Payload and the construction materials are commonly used, safe materials: plastics, copper wire, printed circuit boards, etc. There are no NAR rules that would cause safety concerns for this payload. The only conceivable danger would be if the rocket exploded and the tiny motor used to turn the mirror became a projectile. With the use of hybrid rockets, an explosion would be virtually impossible as the fuel grain is not an explosive material.

4.4.d Discuss any environmental concerns

The firing of a hybrid rocket has a minimal impact on the environment. The major combustion products are carbon dioxide, water and heat. No waste material will be left at the launch site, assuming the rocket is reasonably intact and can be located. There is the danger of fire before liftoff. However, proper safety procedures greatly minimize the chance for a fire at launch.

V. Launch Operations Procedures

Section 5

Launch Operations Procedures

5.1 Checklist

5.1.a Recovery Preparation

Step 1: Ejection charges connected and installed.
Step 2: Shock cords connected between nose and electronics bay and electronics bay and aft section
Step 3: Wadding installed.
Step 4: Parachutes and shock cords carefully folded and packed in recovery bays, along with Kevlar parachute protectors
Step 5: Airframe assembly/integration.

5.1.b Motor Preparation

(From Contrail Rockets Assembly Manual)

Step 1: Ensure that your motor hardware is clean and free from grease, oils, dirt and debris. Wipe the motor components with soap and water, to cut any residual grease from previous firings. Make sure you have all required tools and parts for motor assembly.

Step 2: Begin by installing all O-Rings onto Nozzle, Injector Baffle, and Bulkhead. All O-rings are Dash Number 223. O-Rings should be free from any cracks, burns or damage.

Step 3: Use Krytox™ grease on top Bulkhead O-rings. Smear Krytox™ over the entire outer cylindrical surface of the Bulkhead. This allows for an easy fit into the motor case. Krytox grease is available from Contrail Rockets and our Dealers.

Step 4: Slide top bulkhead into the top side of the motor case. (The top of the motor case does not have an external groove cut into it for a thrust washer). Once the bulkhead is pushed just below the snap ring groove, install the snap ring using snap ring pliers.

Step 5: Install Parker Press-Lock Fitting into the Floating Injector. (The Floating Injector is denoted by an "I" Stamped on the top face) This should be done with a deep wall socket set. Make sure the injector is tightened to ½ turn past snug. To verify injector speeds and Igniter requirements please view the attached chart.

Step 6: Verify that you have the correct size and number of Pyrodex Pellets for your reload and then slide the igniter wire through the center hole of the pellet. Bend the resistor to the side of the powder pellet as shown. For Single Injector 54mm Motors We recommend (2) 50 Caliber/50 Grain Pyrodex Pellets. For Multi Injector Motors We Recommend (3) 50 Caliber/50 Grain Pyrodex Pellets. Ensure that you have placed the Resistor 90 Degrees away from the Nylon Line. This ensures proper ignition of the Pyrodex Pellet Before the Line Bursts. The Pyrodex Pellets should be taped together and it is recommended that 2 wraps of Electrical tape should be sufficient over the entire igniter assembly to ensure ignition. Too much can be a bad thing and cause the pellets to burn too fast.

Step 7: Make sure the nylon line is cut square. If it is not, use a set of cutters to square off the end of the lines. Once the line is cut square, push the line into the Press Lock Fitting. Be sure that you feel the fitting go past an O-Ring seal and seat snugly onto the bottom of the fitting. Once Seated give a slight pull to ensure the fitting is locked in, and the fittings "Teeth" grab onto the line.

Step 8: Now that the Injector and Igniter assembly is put together, you will be greasing the Injector Assemble with Krytox™ Grease just as you did with the top bulkhead. Once the Injector is greased you will slide the assembly into the motor tube. Be sure to not slide the injector up to far, as you will use the grain to push the injector up the rest of the way into the case.

Step 9: Find the included Fuel Grain which came with the reload package. Grease the outside of this grain with a non-petroleum based grease. We recommend Mobile 1 Synthetic Grease. Completely cover the grain with grease before sliding the grain onto the fill line and igniter wire.

Step 10: Slide the Fuel grain into the motor case by pushing it down, which will also push the injector assembly into position as well. Wipe any excess grease off of the outside of the motor case.

Step 11: Find the graphite nozzle with O-ring and give a light coat of synthetic grease. You then want to slide the graphite nozzle into the motor case. Following the insertion of the nozzle into the motor case you will then place the nozzle washer onto the face of the nozzle.

Step 12: Be sure that the nozzle and nozzle washer are pressed slightly below (approx. $1/16^{th}$ of an inch) the snap ring groove. Find the second snap ring, and insert the snap ring into the groove to complete motor assembly.

5.1.c Igniter Installation

Igniter is installed in step 8 of the motor preparation. As the hybrid motor we are using is inert until filled with nitrous oxide on the launch pad this is a safe procedure.

5.1.d Setup on Launcher

Step 1: Set rocket on launch guide
Step 2: Attach oxidizer fill line from fill tank to tube attached to hybrid motor
Step 3: Connect to the motor igniter leads to ignition system
Step 4: Turn on all onboard electronics
Step 5: Verify proper signaling pattern on each electronics subsystem in turn.
Step 6: Activate telemetry receivers and ground electronics. (If an electronics system is functioning unusually, power down
Step 7: Open primary valve on nitrous oxide fill tank
Step 8: Arm ignition system

5.1.e Launch Procedure

Step 1: Remotely fuel motor with nitrous oxide, confirm venting.
Step 2: Be sure range is clear of people, airplanes, helicopters, other hazards.
Step 3: Notify range personnel to begin countdown
Step 4: at “three” discontinue filling with nitrous
Step 4: Ignite motor
Step 5: Visually track rocket ascent and parachute deployment, confirm telemetry reception.

5.1.f Troubleshooting

Problem: Fill is activated on remote control but nitrous oxide does not begin filling the motor.
Solution: Ensure that the control system is armed and that nitrous fill tank is open.

Problem: Coupler and body tubes fail to fit together at launch site.
Solution: Sand coupler tubes and heat body tubes with hot air gun until desired fit it attained.

Problem: Motor fails to ignite.
Solution: Replace faulty igniter or use ignition system with higher power.

Problem: Nitrous oxide leaks out nozzle.
Solution: Replace o-rings and add more krytox to the floating injector.

5.1.f Post Flight Inspection

Inspect for damage:
a) Motor hardware and retainer,
b) Rocket body and fins,
c) Science payload and fiber optic cable,
d) Recovery harness.

5.2 Safety and Quality Assurance

5.2.a Data Demonstrating risks are at acceptable levels

Of at least 8 tests of our hybrid motors on our test stand all have fired successful when properly assembled. Of the 7 flights we have used hybrid motors in, all were recovered without damage accept one. The one failure was caused by an electronics malfunction due to a untested electronics bay design. These results give us confidence in the safety of our hybrid motors.

Our rocket built for this competition has been fired and recovered with no damage using a hybrid motor and the recovery electronics that is will contain at the competition launch. This shows to us that our airframe is flight worthy and that our electrons work with it without malfunction.

5.2.b Risk assessment for launch operations, including proposed and completed mitigations

Several failure cases of the propulsion system exist. A failure of the hybrid rocket motor subsystem would include three scenarios, and a failure of the support system would include one scenario.

The first scenario would be a catastrophic failure of the motor. The Harding University USLI team has been building hybrid rocket motors from Contrail Rockets for three years. We will observe and follow all procedure in constructing and launching our motor; a catastrophic failure is highly unlikely given proper construction procedure. Clearly, such a scenario would completely compromise the launch vehicle.

The second scenario would involve an incomplete fill of the nitrous oxide tank, which occurred the first season that Harding submitted a launch vehicle to the USLI competition. This scenario poses no risk to safety, assuming no other systems fail, but the rocket would not reach the target altitude. The possibility of this failure risks absolutely compromising the success of the mission. This scenario will be avoided by using binoculars to observe the vent line of the motor, and to only ignite the motor when nitrous has been venting for several seconds. The motor must be ignited immediately after the fill is turned off, so arrangements will be made with the Range Safety Officer to allow a shortened count-down (as was done last season).

The third and fourth scenarios both involve a failure to ignite, whether in the third case by a failure of the motor itself or in the fourth case by a failure of the support subsystem. Both scenarios will present the same characteristics, and in both, the Safety Officer will disconnect the ignition line from the support subsystem and report to the Range Safety Officer.

Several failure cases of the recovery system also exist. A failure of the avionics subsystem would involve two scenarios, and a failure of the parachutes subsystem would involve one scenario.

The first scenario would involve an early firing of an ejection charge during ascent. As was witness last season, such an event creates forces on the rocket that cannot be sustained, and the system would lose structural integrity and become a safety concern. In order to mitigate this risk, redundant avionics subsystems are employed, and the barometric altimeter flight computer (MAWD) will have ejection-charge firing locked out until after the motor burn is finished. The LCX flight computer detects apogee with an accelerometer, and will not fire if the rocket is still coasting upwards.

The second scenario would involve a failure of an ejection charge to separate and deploy a parachute. There are three cases: Failure to deploy drogue, failure to deploy main, and failure to deploy any. The first case would likely result in an extremely large impulse on the launch vehicle, and the recovery harness or the airframe would certainly lose integrity. This would result in subassembly component entering free-fall from 800 feet, which would be hazardous to all bystanders. The second case would result in a slowed descent of the vehicle to the ground, which would allow bystanders ample time to avoid, but the velocity of impact would likely damage components of the payload. The third case would result in a ballistic trajectory of the launch vehicle, which would be very hazardous to all bystanders and personnel. In order to mitigate these risks, the redundant avionics system has been employed, and thorough bench testing of both flight computers will occur.

The third scenario would involve a failure of a parachute to open due to tangling or some other circumstance. This scenario can usually be avoided by following the manufacturer's folding and packing instructions, and by leaving the interior of the parachute section free from anything the fabric or shock cord could catch on.

No hazardous chemicals are to be employed in this launch vehicle. The hybrid rocket motor components are completely inert until ignition, and are safe to handle in any situation until fully assembled and upright. The many legal and safety concerns associated with solid fuel ammonium perchlorate motors are not issues when using hybrid motors. Standard range safety procedure will be followed when igniting the rocket motor; this should prevent any danger to personnel and bystanders.

Care must be taken in the assembly of the ejection charges, as an accidental detonation could be hazardous. Hot gas and ejecta from a charge detonating in an unsealed airframe section would be harmful to personnel, so when ejection charges are being attached to the flight computers, all unnecessary personnel will be instructed to stand clear. When in transport, the leads of ejection charges will be twisted together, to prevent ignition by static discharge.

5.2.c Discuss Environmental Concerns

One of the reasons for current interest in hybrid rocket motors (and, incidentally, for our study of hybrid rocket motors) is the environmentally friendly products of a burn when compared to solid and liquid fuel motors. We are confident that the Contrail Rockets K-265SP motor will have a minimal impact on the surrounding environment. The major combustion products are carbon dioxide, water and heat. No waste material will be left at the launch site, assuming the rocket is reasonably intact and can be located. There is the danger of fire before liftoff. However, proper safety procedures greatly minimize the chance for a fire at launch.

5.2.d Individual that is responsible for maintaining safety, quality and procedures checklist.

Greg Lyons, the safety officer, is responsible for maintaining safety, quality and procedures checklist.

VI. Activity Plan

6.1 Budget Plan

Item	Amount
Rocket Airframe	300.00
Parachutes and Safety Harness	100.00
Construction Hardware and Consumables	200.00
Perfect Flight MAWD	100.00
Materials for Science Payload	600.00
Contrail Rocketry Hybrid Motor System and Reloads	500.00
Nitrous Oxide, Motor Fuel Grains, Launch Consumables	300.00
NAR Level 1 and Level 2 Licensure	200.00
Outreach	100.00
Travel to Competition Launch at Marshall Space Flight Center (10 Travelers)	2600.00
Total Estimated Expense	**5000.00**

6.2 Timeline

October 8

- Proposal Due

October 20

- *Proposal Submitted Late*

October 24

- Notification of Selection

October 29

- Finalize Rocket Design and Drawings
- USLI Teams Teleconference

November 12

- Establish Web Presence
- Select Scientific Payload Design; Signal Type

November 28

- Finalize Telemetry and Data Acquisition Scheme
- Preliminary Design Review Report Due

December 3

- Scientific Payload Design Complete

December 5

- Launch Vehicle Design Complete

January 22

- REMSPEC Manufacture Complete
- Recovery Subsystem Verification (Bench Test)
- Data Acquisition Subsystem Verification (Bench Test)
- Telemetry Subsystem Verification (Bench Test)
- Tracking Subsystem Verification (Bench Test)
- Critical Design Review Presentation Slides and CDR Report Due

January 30

- Propulsion Subsystem Verification (Test Stand Firing)

Early February

- NAR Level Two Certification Flight Attempts

January 28 – February 6

- Critical Design Review

February – March

- Test Flights of Competition Rocket
- Phasing In of Systems as they are Completed

February 6

- Launch Vehicle Airframe Manufacture Complete

February 13

- Airframe & Recovery Subsystems Verification (Test Flight)
- REMSPEC Subsystem Verification (Bench Test)

February 20

- Integrated Scientific Payload Verification (Bench Test)
- Integrated Scientific Payload Verification (Bench Test)

February 27

- Integrated Systems Verification (Test Flight)

March 18

- Complete Test Flight of Rocket in Competition Format
- Finalize Report on Motor Thrust Studies
- Flight Readiness Review Presentation Slides and FRR Report Due

March 25 – April 3

- Flight Readiness Review

April 17

- Flight Hardware Check

April 18

- Launch Day

May 8

- Post-Launch Assessment Review Due
- Finalize Report on Exhaust Plume Studies

May 25

- Announcement of Winning USLI Team

6.3 Outreach Summary

On December 2, 2008, Outreach Team member Cortney Owen and Team Official Ed Wilson held a water-bottle rocket competition afternoon for the fourth grade class at Westside Elementary in Searcy, Arkansas. Earlier in the semester, Owen and Wilson had visited the fourth grade classroom of Ms. Sherry Wilson (no relationship) to show the students how to build their rockets and to tell about NASA'sthe Mission to the Moon. They also explained about the USLI 2009 competition in which we were involved. The students and many parents were present for the competition. Prizes were given for the best design, highest flyer, longest hang time and most unique rocket. In all 20 students successfully flew and recovered their rockets. Three landed on the roof of the school and one hung in a tree. This only added to the excitement. Many of the parents and children expressed thanks for having this wonderful hands-on experience in science. Ms. Wilson, the teacher, was also very appreciative and felt the entire project was a huge success. Wilson and Owen were amazed at the skill level achieved by fourth graders in building their rockets. A reporter from the local newspaper was present and will publish an article with picture of the event.

We have contacted the Arkansas Wing of the Civil Air Patrol and are working with them to develop a high school rocket program for them which would lead to their competing in the high school rocket competition at Marshall Space Flight Center. Our contacts are Captain Frank Warner, Director of Aerospace Education (fcwmjw@msn.com) and Morris Middleton, 42nd Composite Squadron, Little Rock (mhmiddleton@gmail.com). We are planning to provide a demonstration and workshop to the Little Rock squadron on how to build and fly a high power rocket. This will involve a minimum of twenty-five students. We will develop a feedback document for the student participants to help in evaluation of our educational outreach. A separate document will be requested from the Wing commander to help assess the impact of our interaction with the Wing.

We will contact the Girls Scouts of Ouachita Council, 100 S. Spring Street, Searcy, AR 72143, phone: 501 279 3085 and offer to provide low power rocket or water bottle rocket programs for the local area Girl Scout troops. We will also offer to help with the scouts to complete requirements for science merit badges. Again, assessment forms will be developed and given to the various participants to get feedback on the program.

We will engage at least one other K-12 school in a rocket activity during the period of this USLI 2009 project.

Press releases will be sent to the *Arkansas Democrat* (Little Rock), *The Daily Citizen* (Searcy) and the Journal of the Gedanken Society (Harding University Chemistry Department) as well as hometown newspapers of the participants.

An article will be submitted to Harding University's school paper, *The Bison*, for publication.

VII. Conclusion

REMSPEC spectra will show the presence, or absence, of the following species commonly found in combustion processes while the rocket motor is being used under normal conditions. See Table 1.

Table 1. Common Species Found in Emission Spectra of Flames

Species	Wavelength Range	Type of Transition
OH	263 nm – 289 nm	A → X OH and CH spectra overlap in this region
OH	306 nm – 324 nm	A → X
CH	415 nm – 440 nm	A → X
CH	386 nm – 404 nm	B → X
C_2	460 nm – 560 nm	d → a
O_2	759 nm – 770 nm	b → X
H_2O	606 nm – 758 nm	3rd overtone vibrational stretch
H_2O	778 nm – 861 nm	3rd overtone vibrational stretch
H_2O	9400 nm – 9700 nm	3rd overtone vibrational stretch
Metals	350 nm – 700 nm	metal impurities at distinct, known wavelengths

Once these species are identified, the areas under the spectral peaks can be used to estimate the concentrations of each one present. The amount of each species can be measured as a function of the burn time.

The designing, planning and reporting involved in an engineering project such as the one reported here is a valuable add-on experience that enhances the learning going on in the classroom. Much valuable experience has been gained by those participating in this exciting project.