USLI Critical Design Review

Hybrid Rocket Design for *In Situ* Exhaust Plume Spectroscopy

Submitted by

The 2008-2009 Harding University "Flying Bison" USLI Team
Searcy, AR 72149
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Section 1

Summary of CDR 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’ 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 PerfectFlite Ejection Charges
1.2.d Rail Size:	> 11 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:	Light from the hybrid motor exhaust plume
1.3.d Output:	Analog signal in time proportional to optical intensity of the portion of the spectrum incident on the photodiode
1.3.e Components:	Fiber optic cable for presentation of light 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 2

Changes made since PDR

2.1 Changes made to Vehicle Criteria

2.1.a No major changes have been made to the vehicle criteria, design, or purpose since the PDR.

2.2 Changes made to Payload Criteria

A small design change has been made to the payload design, although the original purpose remains unchanged.

2.2.a The path of the light from the fiber optic cable has been folded through the assembly with the introduction of several simple mirrors; this serves to minimize the size of the package as well as simplify integration with the rest of the vehicle.

2.3 Changes made to Activity Plan

Due to several setbacks in arranging launch dates, the loss of a key product order, and complications involving the hybrid motor test stand, all activities listed on the timeline have been rescheduled to later times. The lack of available work time between the PDR and the CDR due to the holiday recess has also complicated scheduling. No activities have been removed or added; an updated timeline may be found in Section 5.1.b.

Section 3

Vehicle Criteria

3.1 Selection, Design, and Verification of Launch Vehicle

3.1.a Mission Statement, Requirements, and Mission Success Criteria

The 2008-2009 Harding University “Flying Bison” ULSI Team is committed to the design, construction, launch, and safe recovery a reusable high-powered rocket for the study of hybrid motor exhaust plume emission spectra, with a target altitude of 5,280 feet.

Critical Requirements for Project per *SOW*

- The vehicle shall carry a scientific payload.
- The vehicle shall deliver the science payload to a specific altitude of 5,280 feet.
- The launch vehicle and science payload shall be designed to me recoverable and reusable.
- Data from the science payload shall be collected, analyzed, and reported by the team following the scientific method.
- A tracking device shall be placed on the vehicle allowing the rocket and payload to be recovered after launch.
- Only commercially-available, NAR-approved motors shall be used.
- All teams much launch their full-scale rocket prior to launch day.

- The maximum amount teams may spend on the rocket and payload is $5000 total.

Mission Success Criteria

- Ignite and fire hybrid rocket motor at launch (no motor failure).
- Sustain structural integrity throughout flight, including landing and recovery.
- Meet payload success criteria (see Payload Criteria, 4.3.b).
- Reach 5,280-foot target altitude with minimal error.
- Separate vehicle at apogee; deploy drogue parachute.
- Separate vehicle at 800 feet; deploy main parachute.
- Recover scientific payload and launch vehicle with only cosmetic damage.

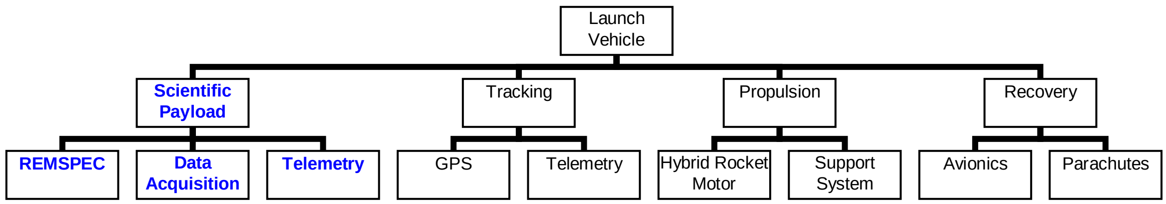
3.1.b Major Milestone Schedule

September 1 – Project Initiation
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)
January 30 – Propulsion Subsystem Verification (Test Stand Firing)
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)

3.1.c Systems and Subsystems

Scientific Payload



The scientific payload is required to collect light from hybrid motor exhaust plume during burn, sample the spectrum of the light as an analog signal in time, store this data in non-volatile memory for later recovery, and transmit this data to the ground wirelessly for analysis in real time. Selection rationale, concepts, subsystems, and performance characteristics are described in Section 4.1.

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.

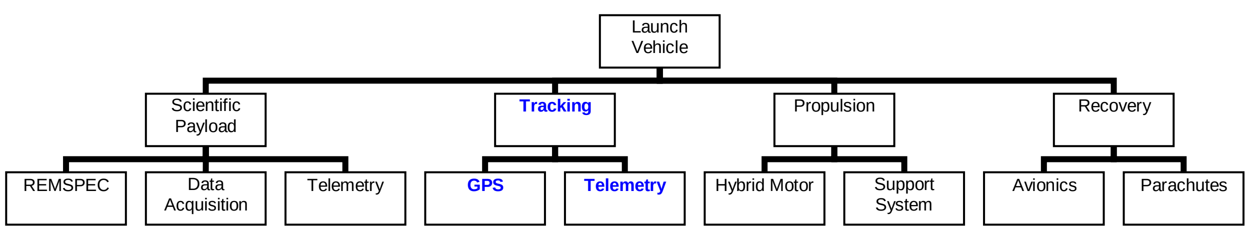
If the data acquisition subsystem fails during flight, the scientific payload will fail absolutely. Once again, this subsystem will be bench-tested to minimize this risk, both against arbitrary analog signals and when interfaced with the REMSPEC.

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.

Testing of the telemetry subsystem will be outlined below. Due to several setbacks and documentation issues, the data acquisition system has not yet been tested. A conference call with the manufacturer is currently being arranged for diagnostic purposes. The REMSPEC has been constructed, and physical testing has occurred. The spectrometer has successfully dispersed light from an LED source, and the spectrum from the source could presumably be collected once the data acquisition system is operational. This testing will be outlined further in Section 4.

Tracking



The requirements of the tracking system are to determine the position of the launch vehicle relative to the launch site throughout the flight, and to transmit this information to the ground to facilitate recovery of the rocket and scientific payload after launch.

The tracking system will continually poll the GPS subsystem for the location of the rocket system, and pass the location to the telemetry subsystem, which will bundle GPS coordinates of the rocket in a packet with other data to be transmitted. This data will be received on the ground and uploaded in real time to a laptop computer for tracking and plotting purposes.

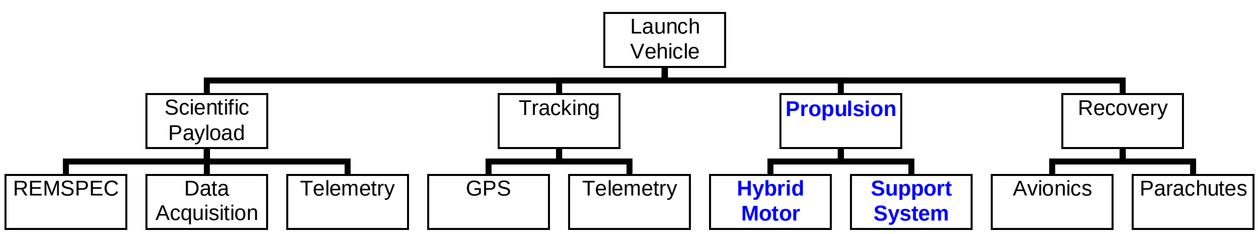
An Eagle Tree Systems (ETS) 5Hz GPS Expander has been chosen as the GPS subsystem. It will interface with the ETS Flight Recorder, which will route the GPS data to the telemetry subsystem. This component has an update rate of 5Hz, which will give approximately 100 data points throughout the flight.

An ETS Seagull-HP 900 MHz 200 mW Transmitter has been selected as the Telemetry subsystem. It will be paired with a Seagull Dashboard Receiver for a 1.2-mile wireless signal range; if necessary, a yagi antenna will be constructed to increase the range by up to 2.4 miles. This transmitter operates in the frequency range of 902 – 928 MHz.

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.

The telemetry subsystem has been tested successfully, and data packets have been sent from the transmitter to the receiver at a moderate range. Unfortunately, software and power issues have complicated testing of the GPS subsystem at this point, and a larger antenna may need to be ordered (a need that was anticipated by the early identification of such a component).

Propulsion



The requirements of the propulsion system are to impart a controlled thrust to the launch vehicle, in a manner conducive to stable flight, which will bring the vehicle to an altitude of 5280 feet with minimal error. The objectives of the scientific payload place an additional requirement on the system; it must employ a hybrid rocket motor.

The propulsion system will ignite by passing a current through an electric match using the support subsystem, which will ignite several Pyrex pellets and begin a controlled oxidation reaction between the nitrous oxide and the fuel grain. This reaction is directed out the nozzle of the hybrid rocket motor, which generates a thrust that propels the rocket. The reactants ejected out of the nozzle are luminous, and can be analyzed with an emission spectrometer (REMSPEC) in order to learn about the reaction in the motor.

A Contrail Rockets K-265SP hybrid rocket motor will be used as the Hybrid Motor subsystem. This motor has a total weight of 2.085 kg, with a recovery weight of 1.814

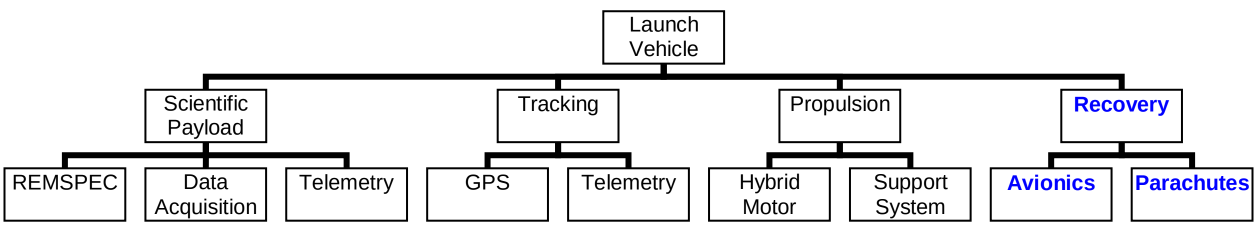
kg, and a nitrous oxide volume of 1490 cc. The burn time for this motor is 6.26 seconds with total impulse of 1684, maximum thrust of 777.1 N, and average thrust of 268.94 N.

A Pratt Hobbies RTLS-M1 Remote Tanking and Launching System will be used as the support subsystem. This module can control the filling of the Hybrid Motor subsystem with nitrous oxide, dump the nitrous oxide from the motor if necessary, and ignite the hybrid motor, all from a location 200 feet away from the launch pad. The igniter generates a 12V across the electric match with a 3000 mAh rechargeable battery.

Failure of the propulsion subsystem clearly presents a great risk to the success of the project; in order to mitigate such risk, the motor will be test fired on our test stand and test flights will be conducted.

A test stand firing of a similar motor, the Contrail Rockets K-234 hybrid, has been postponed due to inadequacies in the test stand design. After the stand has been modified to meet safety and size requirements, a test of both the K-234 and the K-265SP will be conducted.

Recovery



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 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 from the PerfectFlite ejection charge kit, which does not require the use of flashbulbs. Pyrex 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.

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-Wis LCX have been bench-tested and verified to be operational. Further testing of the avionics subsystem will occur when scheduled NAR Level Two certification flights employ both components in their own recovery systems. The order placed for ejection charges to PerfectFlite was either lost or inadvertently cancelled, and a new order has been sent out, which has not arrived at the time of this report. Testing of the necessary mass of Pyrex powder will occur as soon as the order is received; these particular charges will be employed in the certification flights for several team members, scheduled to occur within two weeks.

3.1.d Remaining Manufacture and Assembly

As of the date of this report, all components of the rocket have been purchased or ordered. Manufacturing that remains includes the construction of the fins, cutting of the fin slots in the boat tail, and laser cutting of the avionics and payload electronics bays. No assembly of the rocket has begun at this point.

3.1.e Integrity of Design

The fin shape chosen is a simple delta design, with three fins placed around the body at 120 degrees from one another. This traditional design has been shown to maximize stability and minimize drag; also, this design is easy to manufacture. The fins will have a root chord length of 8", a tip chord length of 4", a sweep length of 4", and a semi-span of 4".

The fins will be each be constructed of two pieces of aircraft plywood, with two layers of fiberglass and a layer of carbon fiber "sandwiched" between the plywood sheets. The bulkheads will be constructed of high-quality plywood purchased from Public Missiles; each bulkhead will consist of inner and outer diameter bulkplates wood-glued together to maximize strength and integrity. The airframe itself will consist of a proprietary polymer from Public Missiles known as "Quantum Tubing," which is both lightweight and durable for subsonic rocket applications. All internal electronics and payload bays are constructed from laser-cut acrylic plastic, cemented with a plastic bonding agent. These bays are not intended to be load-bearing, but are still reinforced with three stainless-steel threaded rods and deliberate internal design characteristics to mitigate all but the most extreme failure scenarios.

From the SolidWorks drawing shown below (Figure [FILL ME IN]), it is clear to see that all load bearing structures are in line with the rocket body, and that no transverse loads exist to cause failure of the airframe. All coupler sections of the rocket, which will house the electronics and payload bays, are affixed to the airframe by six nylon bolts (stainless steel is not chosen for safety reasons). Once the load is transferred to the body of the rocket, the Quantum tubing can bear the compression loads applied easily. The motor mount tube is the only exception, being affixed internally to the aft airframe by four centering rings and epoxy bonds. In order to ensure the strongest possible bonds, the interior of the airframe will be sanded and cleaned before applying the epoxy, and generous amounts of this bonding agent will be used. Moreover, the boat tail will serve to transfer some of the load from the motor to the end of the Quantum tubing in the aft airframe, and it will also be securely affixed to the motor mount with the same technique.

In terms of the fins, the standard through-the-wall mounting will be employed, which involves building a tab onto the base of each fin. Slots will the cut through the boat tail, and the fins will be inserted through the boat tail and bonded directly to the motor mount tube. A centering ring will also be attached such that the front end of the fin tabs inside the rocket airframe will be bonded against it. This mounting method will ensure the fins will remain attached to the rocket under all but the most extreme scenarios.

The nose cone of the rocket will be affixed to the fore airframe with six nylon bolts, and

In addition to the methods described above, the motor mount will be ensured by three techniques: First, a forward-retention ring is installed on the rear of the rocket motor, which will transfer most of the load from motor firing up the motor mount tube. Second, a HAMR (Highly-Adaptive Motor Retainer) will be affixed to the small part of the motor mount tube protruding from the base of the rocket, which will screw on to the end of the tube and prevent any reverse loss of the motor after firing. Third, the motor will be wrapped in masking tape and friction fit into the motor mount tube firmly, so that the force on the tube from the motor will not originate solely at the very end.

3.1.f Dimensional Drawings

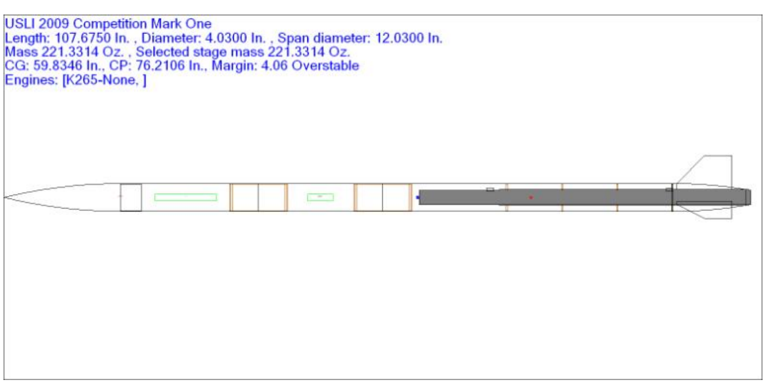


Figure 3.1 Dimensional Drawing of the Launch Vehicle.

The brown section on the left side of the drawing houses the avionics subsystem; the brown section to the right houses the scientific payload and tracking systems. The leftmost section with a green rectangle houses the main parachute; the right section with a green rectangle houses the drogue. The blue dot in the diagram represents the center of mass of the vehicle, and the red dot represents the center of pressure.

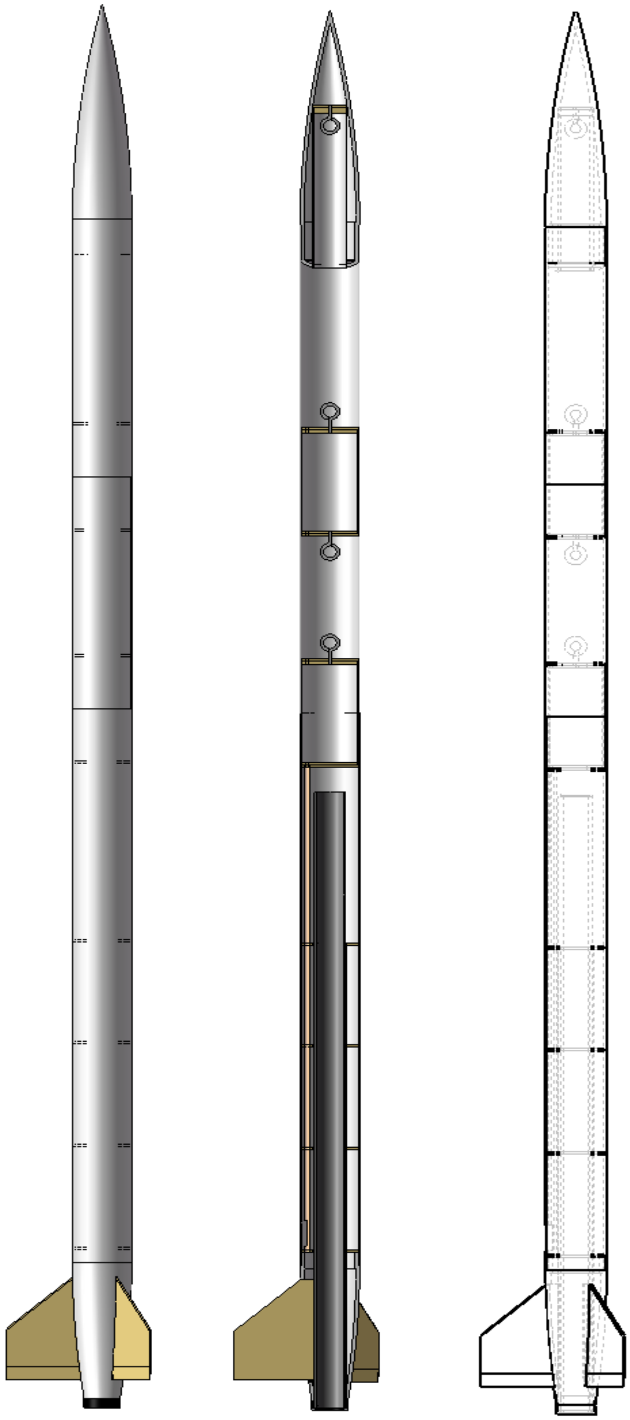


Figure 3.2 SolidWorks Renderings of the Launch Vehicle

3.2 Mission Performance Predictions

3.2.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.

3.2.b Simulations

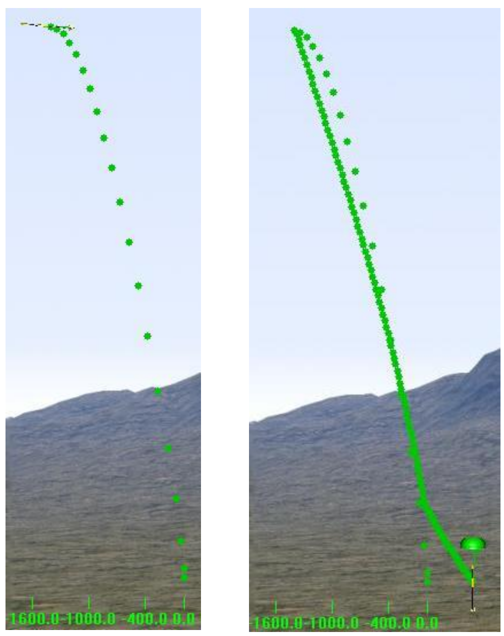


Figure 3.4 Plots of Simulated Flight Profile.

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 5800 feet. While this simulation factors in the masses of each component as best as can be predicted, from experience, the mass of the rocket will be greater in reality. The simulated mass was approximately 14 pounds. This simulated altitude gives a large, comfortable margin for additional weight in case of unforeseen manufacturing complication and hidden weight (e.g. epoxy).

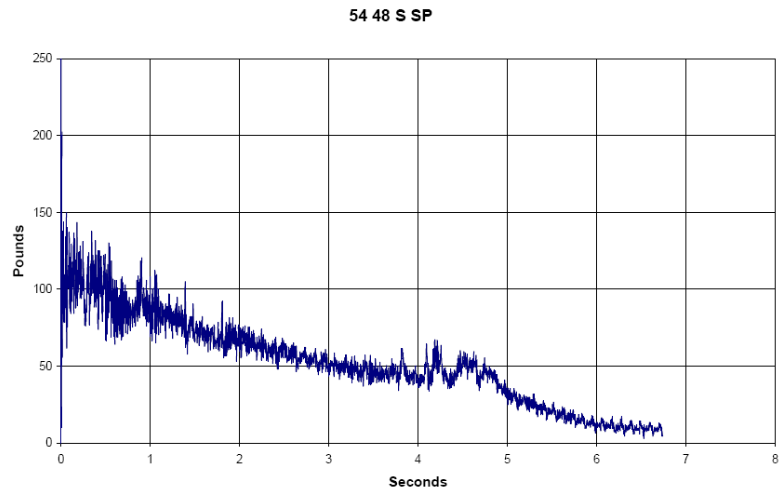


Figure 3.5 K-265SP Thrust Curve.

This 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

Flight resolution: 1000.000000 samples/second

Descent resolution: 500.000000 samples/second

Method: 4th Order runge-kuta.

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: 96.0000 In.

Velocity at launch guide departure: 58.0606 ft/s

The launch guide was cleared at : 0.276 Seconds

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

Minimum velocity for stable flight reached at: 55.5883 In.

Max data values:

Maximum acceleration:Vertical (y): 286.170 Ft./s/sHorizontal (x): 6.297 Ft./s/sMagnitude: 286.171 Ft./s/s

Maximum velocity:Vertical (y): 595.9363 ft/s, Horizontal (x): 21.8533 ft/s, Magnitude: 606.2111 ft/s

Maximum range from launch site: 1373.97586 Ft.

Maximum altitude: 5830.63167 Ft.

Recovery system data

P: Main Deployed at : 99.337 Seconds

Velocity at deployment: 64.2717 ft/s

Altitude at deployment: 699.98236 Ft.

Range at deployment: 87.05065 Ft.

P: Drogue Deployed at : 19.483 Seconds

Velocity at deployment: 75.5806 ft/s

Altitude at deployment: 5830.63166 Ft.

Range at deployment: -1373.97586 Ft.

Time data

Time to burnout: 6.260 Sec.

Time to apogee: 19.483 Sec.

Optimal ejection delay: 13.223 Sec.

Landing data

Successful landing

Time to landing: 133.974 Sec.

Range at landing: 511.20195

Velocity at landing: Vertical: -19.8503 ft/s , Horizontal: 13.7171 ft/s , Magnitude: 24.1287 ft/s

3.2.d Stability Predictions

Returning to the drawing in Section 3.1.d, 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 59.8 inches from the nose of the rocket; the simulated center of pressure is located at 76.2 inches from the nose of the rocket. The resulting stability margin is 4.06 body diameters overstable, which increases to 5.20 as the rocket motor expends its fuel.

With a user-specified stable-flight velocity of 44 ft/s, the rocket reaches the velocity for stable flight at 5 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.

3.3 Payload Integration

The need to integrate the scientific payload system (and the other subsystems) is understood; the REMSPEC has been designed as a <3.9” OD cylinder to allow the instrument to be fit into a coupler tube section. In manufacturing of the airframe, a piece of aluminum tubing will be run through small holes in the centering rings alongside the motor mount tube, to allow a fiber optic cable access to the exhaust plume for collection of light. The data acquisition and telemetry subsystems will also be housed in a similar, adjacent cylinder custom-cut to hold all components in proper orientation. Both the REMSPEC and the other subsystems will simply be detached from the airframe by removing the six nylon bolts, and then slid out of the airframe for easy inspection and operation.

Structurally, the launch vehicle will be designed to fly without the scientific payload and tracking systems; this scenario will actually occur during the first test flight. These systems will be housed in an 8” section of fiberglassed coupler tube between the motor mount and the drogue parachute sections. Three ¼” stainless steel threaded rods will run through the tube and affix the bulkheads firmly to each end.

3.4 Launch Operation Procedures

3.4.a Launch System

The support subsystem will provide all necessary hybrid motor support, including an oxidizer fill control and ignition. What type of launch system will be used must be discussed with the panel members and support team in order to determine what launch guide types will be available at the launch event. If the panel is uncertain, the launch vehicle will be designed to launch off both a rod guide and a rail guide.

3.4.b Final Assembly and Launch Procedures

1. Upon arrival at the launch site, meet with range personnel and determine the launch system to be used.
2. Build ejection charges and position *disconnected* in the airframe.
3. Fold and pack parachutes, shock cord, and flame-resistant materials into rocket.
4. Build hybrid rocket motor; mount into launch vehicle.
5. Power up scientific payload and tracking systems, interface with laptop, and determine operational status.
6. Test telemetry subsystem.
7. Connect ejection charges to avionics subsystem; use flight computers to test continuity on all charges.

8. Assemble sections of airframe and insert power pins to avoid draining batteries during wait.
9. Report ready status to range personnel.
10. When cleared, set rocket on launch guide and attach oxidizer fill line to the support subsystem.
11. Check igniter leads for “disarmed” state, and then connect to the motor igniter leads.
12. Remove power pins to activate all electronics.
13. Report to range personnel.
14. When cleared, fill hybrid motor with nitrous oxide using support subsystem until venting of fluid occurs.
15. Notify range personnel to begin countdown.
16. At “three,” discontinue filling nitrous.
17. Ignite motor.
18. Track rocket during flight visually for safety.
19. Recover rocket.

3.4.c Recovery Preparation

In order to prepare for recovery of the launch vehicle, two designated team members will keep visual contact with the vehicle at all times during flight, and will check with the data handling team member in the event the real-time tracking information becomes necessary for location of the vehicle. Once the RSO has given an all-clear for the launch area, the team members will head directly toward the final resting point of the launch vehicle, using a GPS device and the last point of visual contact as references. These team members will then recover the vehicle and return it promptly to the team.

3.4.d Motor Preparation

The pre-launch assembly of a hybrid rocket motor does not present any notable safety hazards, as all components used (excepting the igniter) are completely inert and safe to handle under any conditions. Special care will be taken in installing the igniter grains, but even when the igniter is introduced, the motor cannot fire, and will not until nitrous oxide is introduced into the motor on the launch pad.

Specific instructions for the assembly of the K-265SP hybrid rocket motor are available on the Contrail Rockets website; the detail of these instructions is too great to repeat here.

3.4.e Igniter Installation

3.4.f Setup on Launcher

Setting the rocket up on the launch will involve three simple steps: First, sliding the rocket onto the guide rail; second, attaching the nitrous fill line from the rocket to the nitrous oxide fill assembly; and third, removing the activation pins from the electronics and payload bays.

3.4.g Post-Flight Inspection

All components of the post-flight vehicle will be inspected for damage, and a detailed list will be made for repair purposes. The data collected from the REMSPEC will be displayed and analyzed, and all attending the launch will be invited to examine the results of the REMSPEC experiment.

3.5 Safety and Environment (Vehicle)

3.5.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.

3.5.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.

3.5.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.

3.5.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.

Section 4

Payload Criteria

4.1 Selection, Design, and Verification of Payload Experiment

4.1.a System-Level Design Review

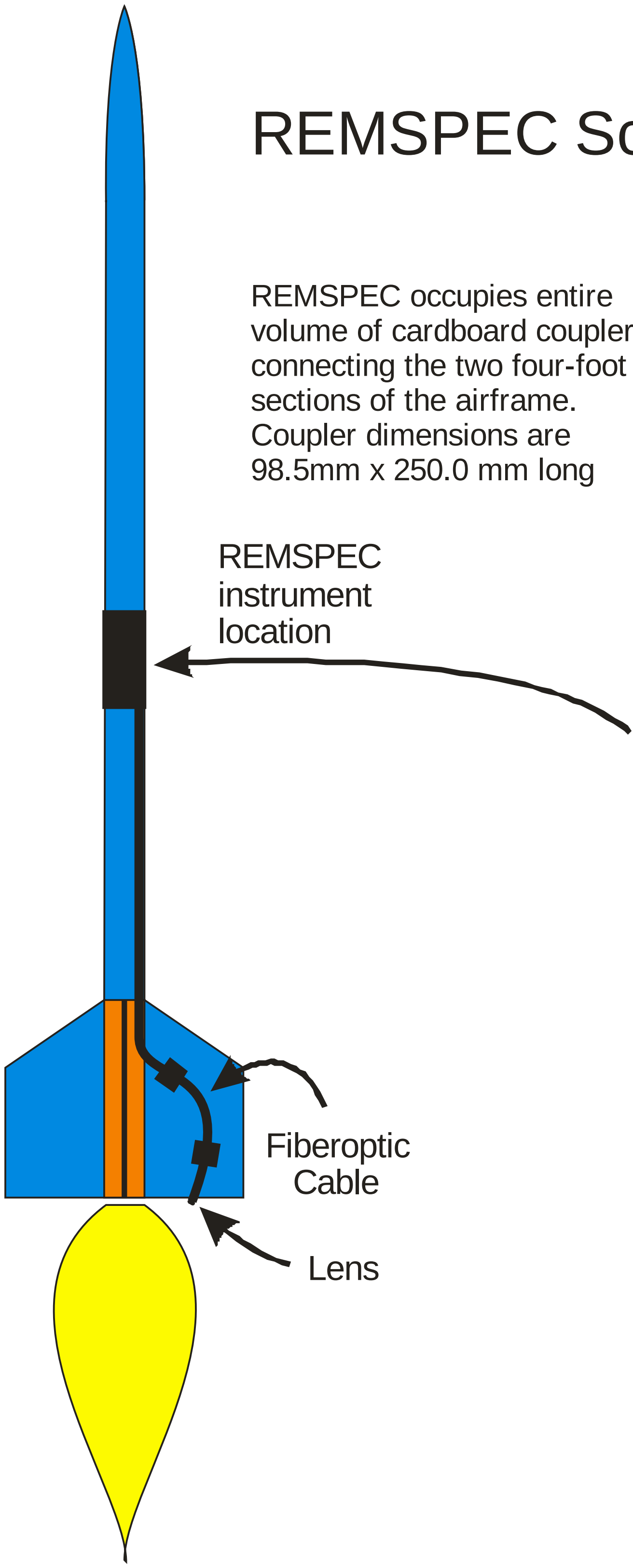
The Science Payload is a ***R***ocket ***EM***ission ***SPEC***trometer, **REMSPEC**, which will measure the emission spectrum of the exhaust plume of our hybrid rocket motor (See Figs. 4.1 and 4.2). A spectral range of 280 nm through 1000 nm will be measured at a rate of five times per second starting 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 the cardboard coupler used to connect the two, four foot 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 is being designed. Fig. 4.4, 4.5 and 4.6 show initial test results of spectrometer.

REMSPEC Science Payload



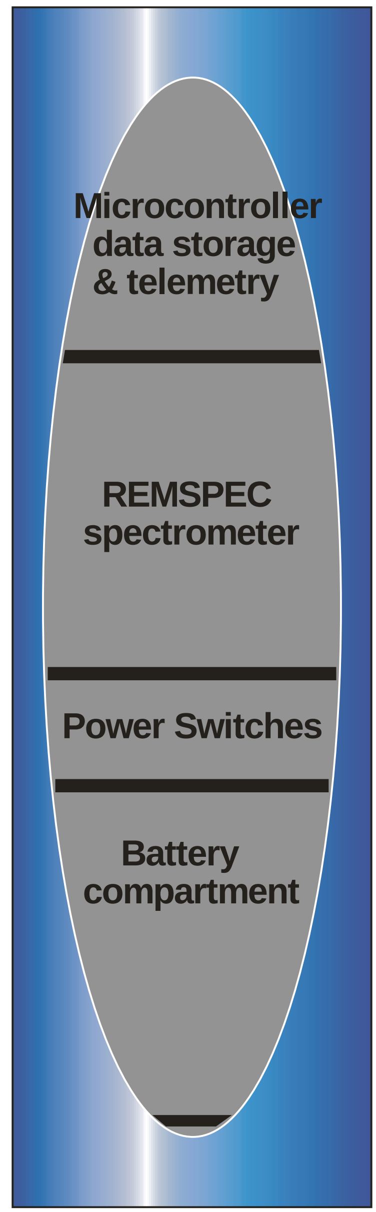


Figure 4.1 Schematic showing REMSPEC location and fiber optic cable placement.

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

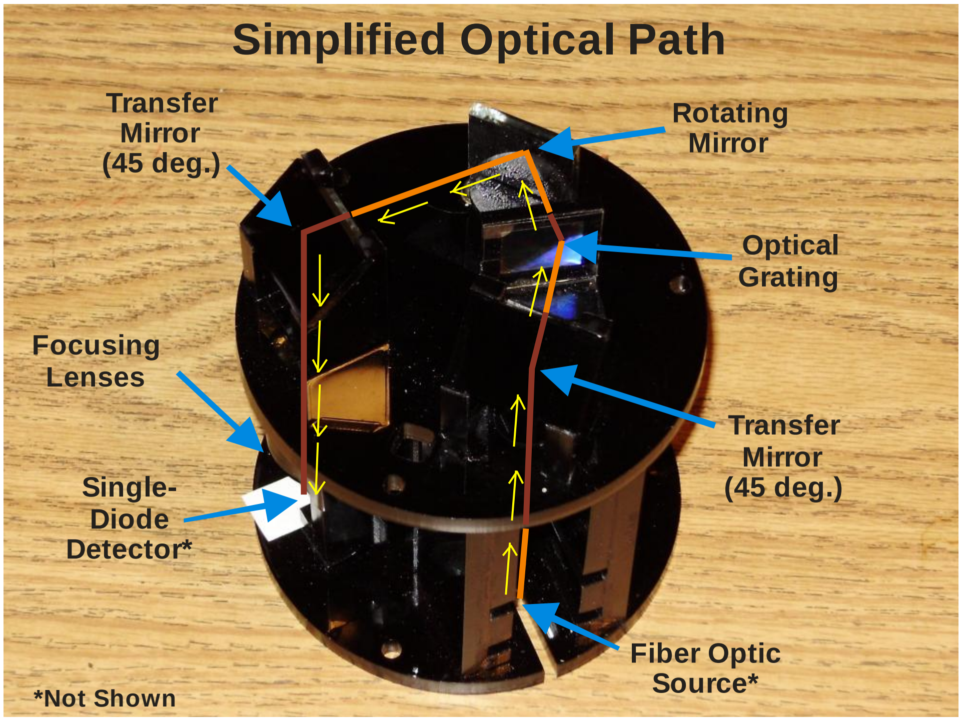


Figure 4.3. Photograph of spectrometer subsystem of REMSPEC. Light beam drawn in to illustrate path of light traveling through the spectrometer. The light beam is folded in order to maintain a large light path while economizing space.

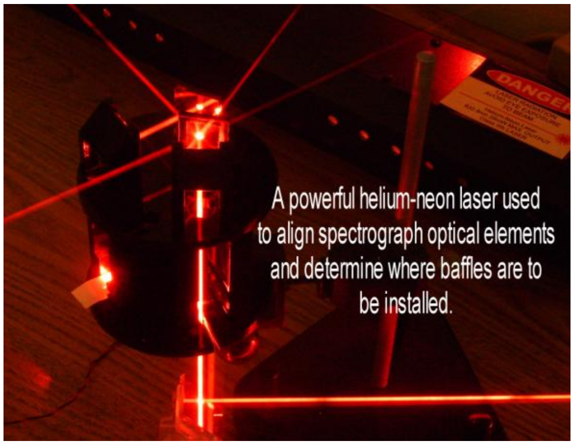


Figure 4.4. Helium-neon laser beam shining into entrance port of spectrometer. This was done to know where to install baffles to remove scattered light and also to check the mechanical alignment of the optics.

Figure 4.5 Spectrum of helium-neon laser showing one red spot. This would be expected since this laser emits a single red wave length, 632 nm.

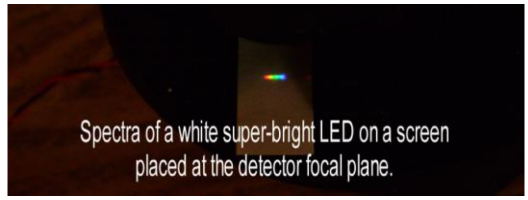


Figure 4.6 Spectrum of Super-Bright LED at the focal plane. The spectrum is clearly visible with with red on the left and blue on the right.

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

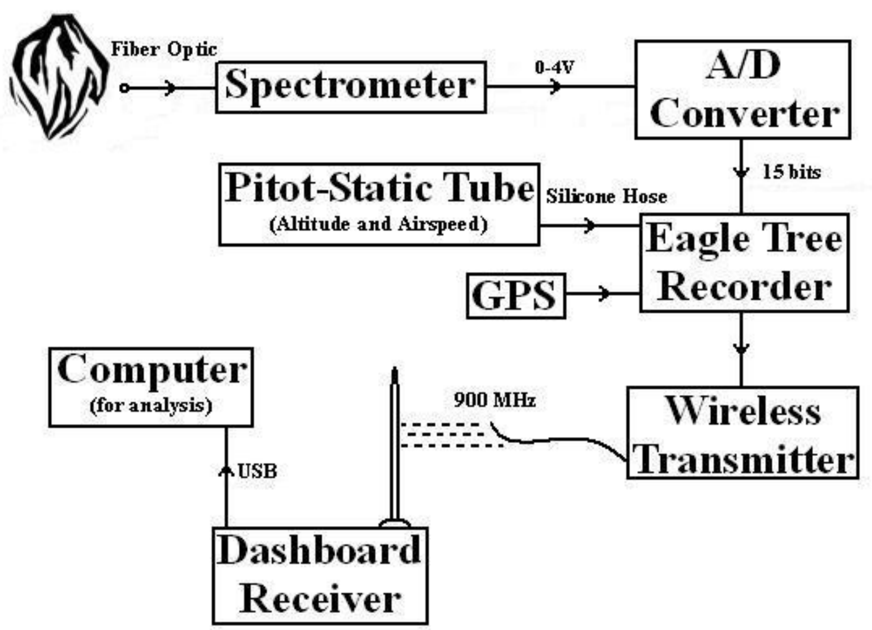


Figure 4.7 Schematic of microcontroller subsystem.

The 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 and weighs very little.

Power supply subsystem – The entire Science Payload operates on batteries. Four AAA batteries that supply 6 VDC at 100 mA for 2 hours are used for the power supply.

4.1.b Performance Characteristics and Verification Metrics

The REMSPEC instrument will measure the spectra of the hybrid rocket exhaust plume five times per second for 6 seconds, giving 30 spectra. The spectra will show the presence, or absence, of the following species commonly found in combustion processes. 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	3^{rd} overtone vibrational stretch
H_2O	778 nm – 861 nm	3^{rd} overtone vibrational stretch
H_2O	9400 nm – 9700 nm	3^{rd} 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.

4.1.c Verification Plan

Before the launch competition in April 2009 at Marshall Space Flight Center, several test firings of hybrid rocket motors will be carried out by Megan Bush, Leader for the REMSPEC subsystem. This will be done on Hybrid Rocket Test Stand 1 at Harding University. Two spectrometers will be used, REMSPEC and another commercial spectrometer that can accurately measure these same rocket firings and serve as the standard. We will be able to verify that REMSPEC is working reproducibly and accurately.

4.1.d Preliminary 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).

4.1.e Instrument Precision and Repeatability

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.

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.

4.2.b Uniqueness or Significance

It is possible that no one has ever employed a spinning mirror spectrometer and the design is unique. The significance of these types of measurements is that it is moving us further to achieving the goals of our rocket research program at Harding University. The first goal is to determine what chemical species are present in hybrid rocket plumes both temporally and spatially as well as determine the amounts. The 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.c Suitable 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 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 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 Variables

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.d Data Relevance and 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.e Experiment 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 Safety and Environment (Payload)

4.4.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.

4.4.b Failure Modes

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.

4.4.c Personnel Hazards

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 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.

Section 5

Activity Plan

5.1 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**

5.2 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

5.3 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, 42^{nd} 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.

Section 6

Conclusion

The 2008-2009 Harding University "Flying Bison" USLI Team has finished the design of their launch vehicle and scientific payload system, and has completed manufacture of all subsystems. Simulations of the launch vehicle in flight show give encouraging flight performance predictions. All necessary manufacturing materials are possessed. The focus after this review will shift toward airframe manufacture and integrated testing, with an expressed goal of a successful test launch of the vehicle in launch configuration by the Flight Readiness Review. The scientific payload, the REMSPEC, currently at the end stages of testing, is ambitious, challenging, and scientifically valuable. The HU "Flying Bison" Team submits this Critical Design Review to the USLI Panel for review and suggestion on Thursday, January 22, 2009.