Preliminary Design Review

I) Vehicle Criteria
Selection, Design, and Verification of Launch Vehicle

Mission Statement
The Harding University USLI Team, in order to advance learning and enhance our overall educational experience, will build and thoroughly document the development of a rocket that will achieve an altitude of five thousand two hundred and eighty feet and recover safely while carrying an electronic payload with scientific and engineering applications that will study the hybrid rocket exhaust plume.

Major Milestones
October 7- Selected payload package
October 23- Teleconference-Proposal review
November 5- Designed the rocket
November 13- Order parts for payload, USLI rocket, scale test vehicle
December 15- Construction of rockets begins
December 22-29- Static testing of ejection systems
January 13- Scale test vehicle launch in Memphis
January 20- Payload testing, integration of electronics with USLI rocket
February 10- USLI system flight test, half-altitude flight (2500 ft. target)
March- USLI system flight test, full-altitude flight (5280 ft. target)
April- Flight
May- Final report

System Breakdown
The external airframe of the rocket will be constructed from Public Missiles phenolic tubing reinforced with 6 oz. fiberglass. An injection-molded plastic nosecone and a SlimLine urethane retainer tailcone give the vehicle aerodynamic contours. A flight computer with a 3-axis accelerometer, spectrograph, GPS board, and telemetry attachments will be supplemented by two altimeters and a self-contained BoosterVision micro camera with transmitter to comprise the payload. The predicted motor of choice is a Hypertek K240 hybrid, though a variety of 54mm, 54mm Hammerhead, and 76 mm hybrid motors in the J-K range from Hypertek, Contrail Rockets, and RATTWorks may be utilized depending on desired flight characteristics and final vehicle weight.

Electronic Deployment and Scientific Payload Subsystems
Our mission involves the use of a few subsystems to complete the tasks we have set for our launch. One system is a R-DAS flight computer, which features a barometric altimeter, 3-axis accelerometer, GPS locator and antenna, data recording capabilities, and a telemetry transmission antenna. This is the primary electronics for drogue deployment and is located at the top of the booster section, above the motor. A fiber optic cable will allow a compact spectrograph to observe the hybrid rocket exhaust plume during flight, and the R-DAS flight computer will record the scientific data as well as transmit it to the ground.

The secondary (upper) electronics bay is located between the drogue and main parachute departments and will hold a pair of redundant electronic controls (an accelerometer/ altimeter combo and a recording altimeter) for drogue and main parachute deployment and additional recording of flight performance data. The upper electronics bay will also hold a Boostervision wireless color 2.4Ghz Wireless Micro Camera that will be mounted to view down the length of the rocket during boost and transmit video to the ground during flight via a separate antenna. The Perfectflite recording altimeter used for competition will also be housed in this bay.

In this way, drogue deployment and airframe separation are triggered by three completely separate and redundant electronics pieces from different manufacturers, using different techniques for sensing apogee, in two different payload bays. Main parachute deployment is trigged by two completely separate and redundant electronics systems. This will minimize the chance of non-deployment and allow an array of scientific and performance data to be gathered from the flight, as well as transmitting spectrographic data and video to the ground for analysis in case the flight vehicle is lost.

Verification

In order to verify the status of the project, our team has weekly meetings where we give status reports on each part of the project. Our team also communicates through e-mail, outside of meetings, so that every team member can remain informed of dates and meeting times. When construction and testing of the rocket begins, progress reports from each separate area of the construction will be submitted to the project leader in a timely manner. This will help the team as a whole meet deadlines and progress towards the completion of the project.

Risks and Mitigation Schedule

Various potential failure modes exist for the competition flight. The most likely scenarios are:

1) **Not enough time for construction**
   Possible causes: Inefficient work process or division of labor, unrealistic timetables.
   Risk mitigation: Planning ahead, developing detailed schedules and assigning enough people to each task.
2) **Components unavailable**
   Possible causes: Out-of-date information from manufacturers, changes in regulatory environment, order components too late for construction schedule.
   Risk mitigation: develop detailed parts lists, avoid using materials with regulatory drawbacks (APCP, thermalite, etc.) order components early, identify problems with manufacturers and shipping and modify design as necessary.
3) **Failure to launch in proper time window**
   Possible causes: Slow rocket and motor assembly, unfamiliarity with ground support equipment and fueling.
   Risk mitigation: Practice dry assembly and perform test launches on smaller scale test vehicle, develop checklists based on previous launches, become familiar with HyperTek or other ground support equipment.
4) **Motor failure (CATO, chuff, etc.).**
   Possible causes: Unfamiliarity with hybrid rocket motor assembly, nitrous loading, ignition procedures, manufacturer's defect.

Risk mitigation: Practice motor assembly and nitrous loading, follow manufacturer's instructions static fire subscale motor on Harding test stand, develop detailed launch procedure checklists to hasten preparation.

5) **Structural failure under thrust (shred)**
Possible causes: Motor mount or thrust plate failure, fin flutter, body tube crimping, coupler failure.
Risk mitigation: Through the wall fin mounting, fiberglass and/or carbon fiber joints between fins and motor mount tube, fiberglass reinforced main airframe, couplers with interior fiberglass reinforcement and 1.5 body caliber insertions.

6) **Recovery failure under thrust (premature deployment)**
Possible causes: Early ejection charge firing due to supersonic discontinuous airflow, poor airframe venting for barometric altimeter, or lack of pressure equalization in parachute compartments.
Risk mitigation: Mach-inhibition on barometric deployment devices, vent holes in parachute sections, multiple vent holes of sufficient size in recovery electronics section.

7) **Recovery failure during coast (premature separation)**
Possible cause: Coupler joints' friction fits too loose
Risk mitigation: Shear-pins on all recovery separation point coupler shoulders.

8) **Failure to deploy either parachute (ballistic reentry)**
Possible causes: Complete failure of electronics, failure to fire ejection charges, insufficient ejection charge size.
Risk mitigation: Multiply redundant electronic recovery systems using different methodologies for sensing apogee (accelerometer vs. altimeter), independent power supplies and ejection charges for each redundant system, pre-flight testing of electronics, ejection charge size with fully packed recovery system, and electronics flight testing in sub scale test vehicle (which will utilize backup motor ejection on a solid fuel G motor).

9) **Partial deployment of recovery system**
Possible causes: incorrect parachute and recovery harness packing, failure of main parachute to deploy after drogue deployment.
Risk mitigation: practice parachute packing techniques and record successful strategies from preflight tests, use redundant electronic deployment controls for main parachute in addition to drogue.

10) **Airframe damage on parachute deployment (zippering, collision)**
Possible causes: poor airframe design or insufficient strength.
Risk mitigation: anti-zipper design of booster section, reinforced airframe.

11) **Deployment of main and drogue parachutes at apogee**
Possible cause: Insufficient friction fit on main parachute separation point coupler.
Risk mitigation: Shear-pins on main parachute separation point coupler, ground testing of black powder ejection charge size with shear-pins installed.

12) **Failure of scientific payload or telemetry**
Possible causes: Weak mounting in payload section, power failures, unfamiliarity with electronics procedures, poor payload bay design.
Risk mitigation: Stress-test electronics mounting on lower-G test flight, sufficient and redundant power supplies for electronic components, preflight testing of electronics payload, telemetry with receiver, ground support electronics and laptop, detailed

procedures for powering up and testing electronics in pre-flight workup, including externally-accessible switches in payload design.

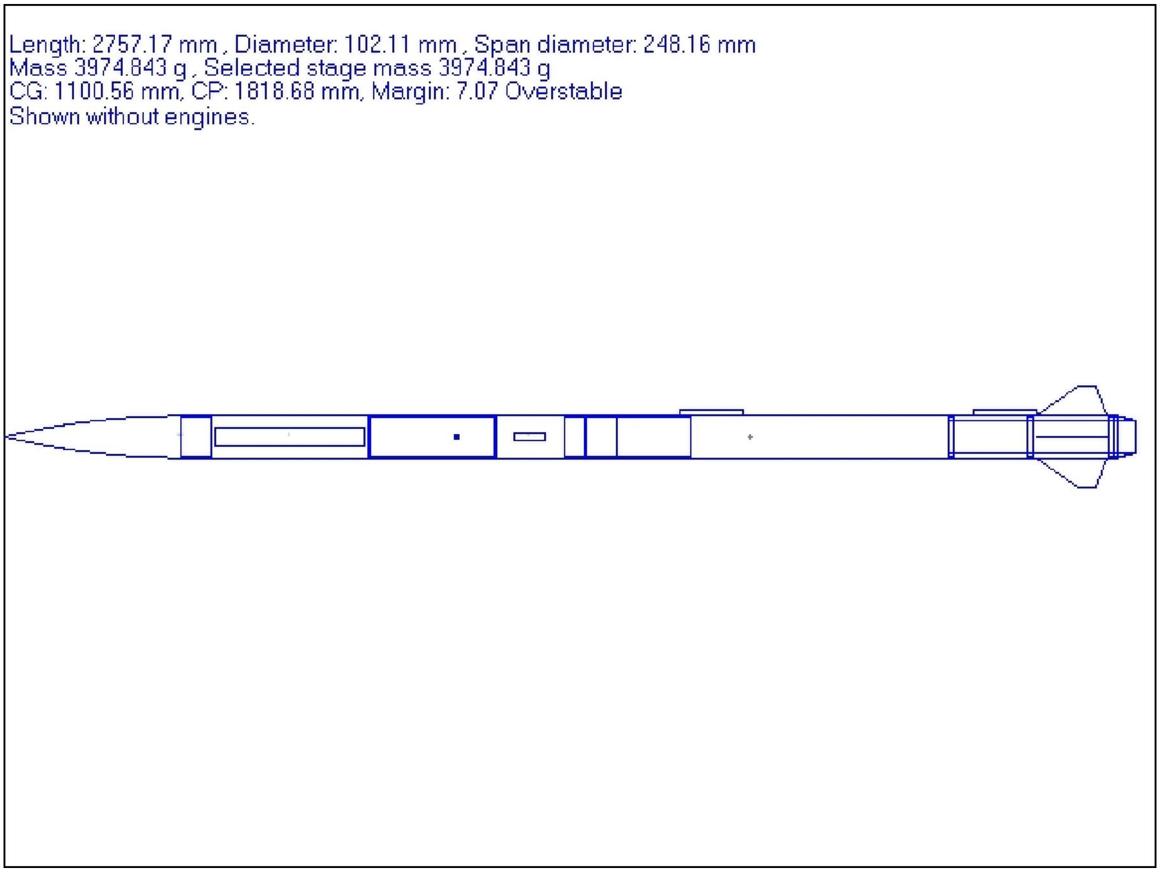
Impact	Probability	Risks	Hazard	Mitigation
Rocket unsuccessful	low	Design	Doesn't meet requirements	Cyclic evaluation and testing of closin parameters
Not enough time for construction	med	Procedure	ordered parts not received in timely fashion	Check availability with multiple supports as possible
Rocket doesn't survive	low	Construction	improper construction	Team leader for construction has significant rocket building experience
Payload doesn't work	low	Payload Function	Payload compounds doesn't work integrate properly	Compounds tested individually Reduced power test checks integrated system
Launch aborts/fails	med	Launch	Fail prelaunch check, no ignition rocket damage	Dry run complete prelaunch sequence, Pre-test ignition system/ recovery system
Parts for system not available	low	Budget	can't buy parts	Obtained extra funds

Modeling and Ground Testing

Our plans for development of the rocket include creating and updating an accurate Rocksim computer model to select parts, and then making adjustments, especially regarding final weights of parts, as construction progresses. The Rocksim model will be used to project performance using different motors. The half-altitude full-up flight test preceding the full-power, full-altitude full-up flight test of the Harding USLI rocket will allow final tweaking of the Rocksim model (especially Center of Pressure calculations) and payload weights to target 5280 feet as closely as possible. Computer predictions for the USLI rocket and its smaller scale test vehicle will be evaluated in comparison to field experience by the Safety Officer, a L2 certified flier.

The electronics subsystems, including ejection charges, will be ground-tested so that multiple team members can become familiar with the operational procedures for the different electronics, and an efficient, thorough pre-flight checklist can be developed that involves multiple team members in the preparation of the rocket, checking each other's work as they proceed. Ejection charge sizes will also be ground-tested to assure the charges are sufficient for energetic separation of the airframe, and that switches and necessary shunts work to prevent premature ejection, such as on the launch pad or during preparation.

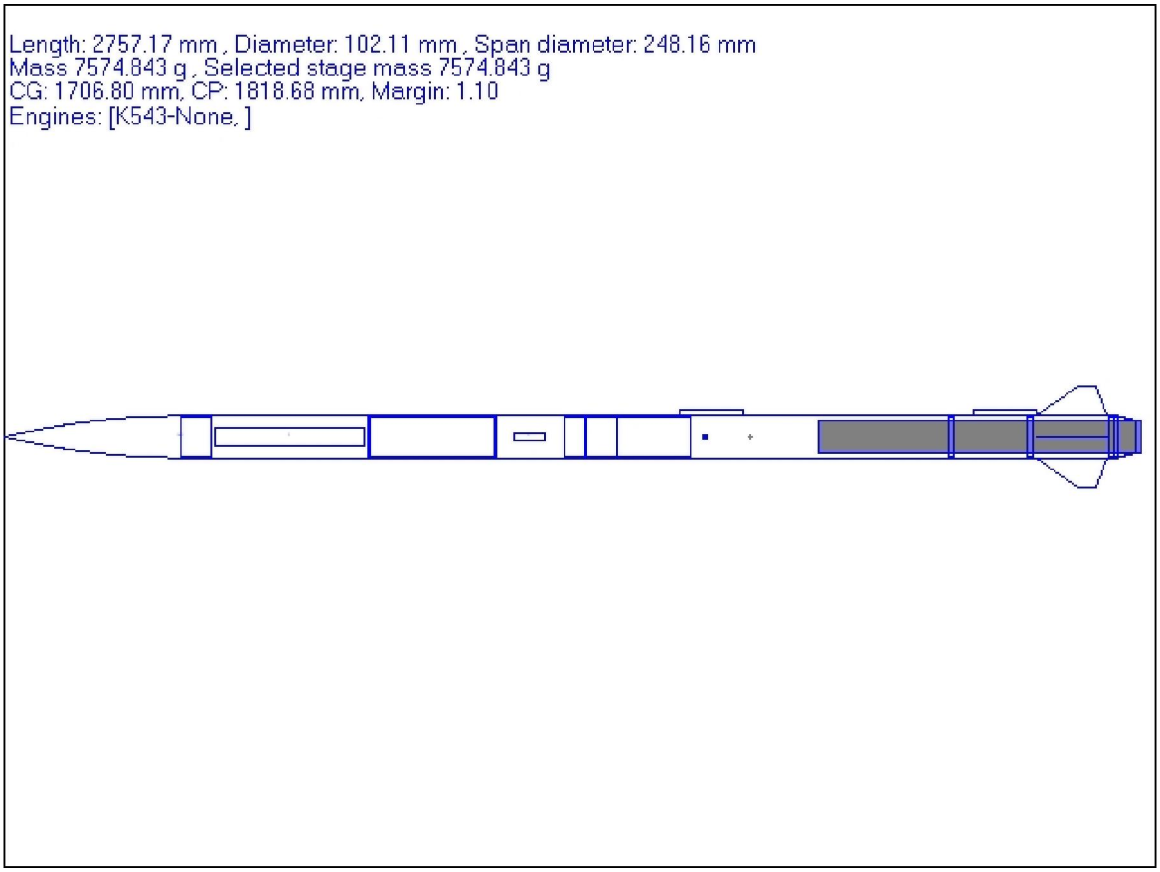
Harding has developed a static facility for 29 and 38mm hybrid rocket motors, which will be utilized to familiarize the team with loading and ignition procedures for a smaller scale hybrid rocket motor of the same brand as that finally selected for flight. RATTWorks, Contrail Rockets, and HyperTek are three manufactures whose products may be selected based on performance criteria and the final weight of the constructed flight vehicle.



RockSim schematic of Harding USLI rocket without motor.

Confidence and Maturity

We will assure the confidence and maturity of design by first simulating each subsystem with appropriate computer simulation software. During construction, appropriate testing of each subsystem by itself will proceed as each subsystem is completed. After construction is completed each subsystem will be tested within the context of the system as a whole.



Harding USLI rocket shown with Contrail Rockets 76mm K543 Hybrid motor

Performance Projections

Initial Projected Performance on selected hybrid motors (based on estimated mass of 3.97kg). Actual weight of rocket will likely vary, and can be modified using removable standard weights in payload bays to adjust final altitude for competition flight.

Manufacturer	Motor	Max Altitude	Max Velocity
RATT Works	J160	2300 ft	322 ft/sec
Hypertek	J317-835CC172J-N	3549 ft	474 ft/sec
Hypertek	K240-835CC125J-N	5710 ft	594 ft/sec
Ratt Works	K240	6553 ft	600 ft/sec
Contrail Rockets	K543	7679 ft	823 ft/sec
Contrail Rockets	K888	8932 ft	970 ft/sec
RATT Works	L600	11949 ft	1258 ft/sec

List of Major Components

Nose cone

Public Missiles PNC-3.90 Plastic nose cone, Material: Polystyrene PS

Nose shape: Hollow Ogive, Len: 16.8000 In., Dia: 4.0000 In. Wall thickness: 0.1250 In. Body insert: OD: 3.8800 In., Len: 3.0000 In., Mass: 10.0000 Oz.

Body tubes
Public Missiles Ltd. PT-3.9 Airframe tube, Material: Kraft phenolic, OD: 4.0200 In. , ID: 3.9000 In., Len: 42.0000 In., Mass: 17.3734 Oz.

Main Parachute
LOC Precision LP-86 86 In. 20 lines, Material: Rip stop nylon, Shape: Round Dia: 85.8268 In., Mass: 16.0144 Oz.

Drogue Parachute
LOC Precision LP-18, 18 In. 8 lines, Material: Rip stop nylon, Shape: Round Dia: 17.9921 In., Mass: 0.8007 Oz.

Launch lugs
Public Missiles LL-0.50 "1/2" brass launch lug, Material: Brass, OD: 0.5000 In., ID: 0.4500 In., Len: 6.0000 In., Mass: 1.1068 Oz.

Fin set
Public Missiles, Material: G10 fiberglass, Planform: trapezoidal, Root chord: 6.7500 In., Tip chord: 1.7500 In., Semi-span: 2.8750 In., Sweep: 4.0000 In., Mid-Chord: 3.2428 In. Misc: Location: 1.0000 In. From the base of Body tube Thickness: 0.0930 In., Mass: 5.0058 Oz.

Centering rings
Public Missiles - CR-3.9-3.0 - Was PML CR-15, Material: Aircraft plywood (Birch), OD: 3.9000 In., ID: 3.1300 In., Len: 0.5000 In., Mass: 2.5031 Oz.

Tailcone
98-76mm Slimline Tailcone Retainer

Recovery Subsystem

Our rocket will use multiple redundant electronically activated recovery systems to ensure safe recovery, as hybrid rocket motors contain no ejection charges.
The following electronics will be incorporated into the recovery and scientific electronic payload bays:

R-DAS Kompact
2-axis Accelerometer and Temperature Sensor Board
GPS unit
Active GPS antenna
6 Channel Telemetry transmitter
6 Channel Telemetry receiver
3 Element Yagi antenna
GWiz MC 2.0 Recording Flight Computer
Booster vision GearCam Mile high combo
RRC2 recording altimeter

We have simulated our rocket on Rocksim based on estimated mass of 3.97kg including the electronics and recovery system. We will have two parachutes, the main and the drogue one.

Parachutes Description:

Main Parachute	Drogue Parachute
LOC Precision LP-86 86 In. 20 lines, Material: Rip stop nylon, Shape: Round Dia: 85.8268 In., Mass: 16.0144 Oz. Estimated descent rate: 15.6 ft/sec	LOC Precision LP-18 18 In. 8 lines, Material: Rip stop nylon, Shape: Round Dia: 17.9921 In., Mass: 0.8007Oz. Estimated descent rate: 74.6 ft/sec

The drogue parachute will be deployed at apogee to facilitate a rapid but controlled descent. The main parachute will be deployed at 800ft by the barometric altimeters to allow for a gentle landing.

Mission Performance Predictions

Satisfactory performance of the Harding USLI launch vehicle will include reaching a maximum altitude of 5280 feet, safely deploying both drogue and main parachutes at the appropriate times, and recovering usable scientific data.

The following Rocksim predictions were run using an estimated mass of 3.97 kg.

Manufacturer	Motor	Max Altitude	Max Velocity
RATT Works	J160	2300 ft	322 ft/sec
Hypertek	J317-835CC172J-N	3549 ft	474 ft/sec
Hypertek	K240-835CC125J-N	5710 ft	594 ft/sec
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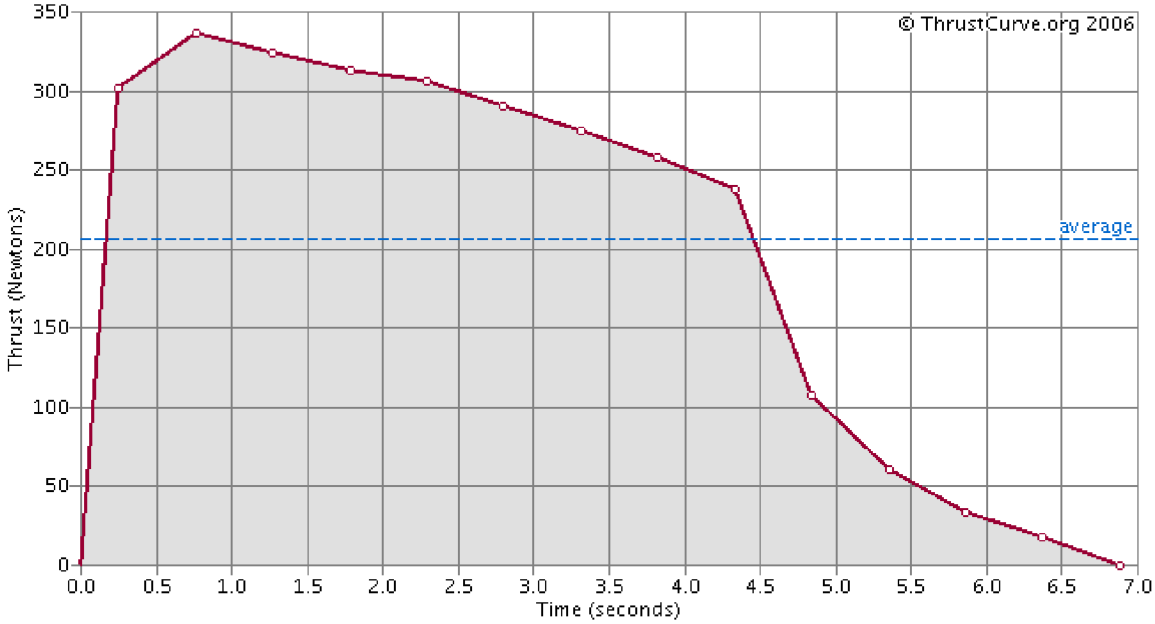
RATT Works	L600	11949 ft	1258 ft/sec

Since Rocksim weight predictions are typically understated (as there are many sources of weight gain during construction, especially when using fiberglass) a variety of motors will be considered. The modular coupler components of the lower and upper electronics bays as well as the nose cone will be modified so as to allow the mounting of standard weights. In this way, the weight of the rocket can be increased within reasonable ranges (and with recovery system modification based on final mass) to bring the predicted altitude closer to 5280 feet.



Thrust curve of Hypertek K240 (from Thrustcurve.org)

Stability Calculations

Rocksim CP estimates, using Hypertek K240 (3.97 kg rocket empty, 5.78 kg loaded)
CG: 1503 mm from nose tip
CP: 1818 mm from nose tip
Margin: 3.1 body calibers

Payload Integration

The electronics and scientific payload will be mounted in two electronics bays. The lower electronics bay is located just forward of the motor mount within the booster section. This bay will house the flight computer with a connected spectrograph. A fiber optic cable will follow from the spectrograph to the tail of the rocket for observation of the hybrid rocket plume.

Within the electronics bay all components will be mounted within a removable 3.9” OD coupler 9 inches in length. A 3”x4” removable access hatch will be installed in the wall of the electronics bay, and each electronic component will have a separate switch installed in the exterior of the payload bay tubing. In this way, the electronics package can be completely removed as a single component in the coupler, accessed during preparations via the access hatch, and activated using external switches, selected for their ability to withstand acceleration and remain locked in place.

The upper electronics bay will house the remaining electronics; altimeters and video equipment. The upper bay will be located between the main and drogue parachute compartments and will be composed of a 3.9” OD coupler 9 inches in length. Like the lower bay, the upper bay will be accessible as a easily removable modular component within the coupler, through an access hatch in the wall of the body tube, and through externally mounted switches for pre-flight activation of electronics systems.

Launch Operation Procedures

For motor ignition using RATTWorks or Contrail Rockets hybrid motors, any standard 12V ignition system will work. Nitrous oxide fueling is accomplished with tanks and connections provided by the manufacturer. Our team already has a nitrous tank and appropriate connections for RattWorks motors.

HyperTek motors use non-pyrotechnic ignition and necessitate complex Ground Support Equipment (GSE) for nitrous oxide fueling and ignition. The NAR chapter with which we are performing test flights has the full HyperTek GSE, which will be used in preparatory flights for team members to gain familiarity with it, and can be transported to the USLI launch site if HyperTek GSE would not otherwise be provided. Nitrous oxide can be obtained on site for a fee.

The USLI rocket is designed to use a standard ½” diameter steel launch rod. A rod of at least 6 feet is preferred. Any standard high power launch pad capable of holding a ½” launch rod will work.

Pre-flight and Launch Process- Brief Outline

1) Assemble hybrid rocket motor.
2) Install rocket motor in motor mount and secure in place using Slimline retainer
3) Fresh batteries placed in all electronics.
4) Electronics physically installed in removable coupler modules
5) Electronics placed in respective payload bays.
6) Electronics tested for proper starting and cycling patterns.
7) Ground support electronics and telemetry receivers tested for proper functioning.
8) Electronics safety switches turned off.
9) Ejection charges connected and installed.
10) Wadding and/or parachute protection pads installed.
11) Parachutes carefully folded and packed in recovery bays.
12) Assemble airframe.
13) Install shear-pins on recovery system separation points.
14) Place rocket on launch pad, erect to vertical.
15) Clear launch area of unnecessary personnel.
16) Turn electronics on using external switches.
17) Verify proper signaling pattern on each electronics subsystem in turn.
18) Activate telemetry receivers and ground electronics.
19) Install hybrid rocket motor igniter and/or fill stem.
20) Evacuate launch pad area.
21) Remotely fuel motor with nitrous oxide, confirm venting if necessary.
22) Be sure range is clear of people, airplanes, helicopters, other hazards.
23) Launch rocket
24) Visually track rocket ascent and parachute deployment, confirm telemetry reception.
25) Recover rocket, secure unfired ejection charges.
26) Post-flight airframe inspection for damage.
27) Process data stored on-board electronics.

Safety and Environment

Safety Officer

Brett Keller, NAR #86412, L2 certified

Analysis of failure modes

See Risk and Mitigation Schedule, above.

Personnel hazards

Nitrous oxide boils at -127° F. It can cause frostbite, as well as its potential dangers as a compressed gas. MSDS available at http://www.osha.gov/SLTC/ healthguidelines/nitrousoxide

Flight operations risks will be mitigated by following the NAR high power rocketry safety code (available at http://nar.org/NARhpsc.html) which all team members have read and pledged to follow, observing recommended safe distances, and following detailed preflight checklists.

Environmental concerns

Hybrid rocket motors are environment-friendly compared to solid fuel ammonium perchlorate motors. Burning inert thermoplastics and nitrous oxide has minimal atmospheric effect. Reusable parachute protection pads and/or biodegradable wadding will be utilized to minimize impact at the launch site. All trash and packaging will be removed from the launch site and disposed of properly.

II) Payload Criteria

Selection, Design, and Verification of Payload Experiment

Payload Concept Features and Definition

The scientific payload is composed of a GPS tracking system, multiple barometric recording altimeters, a 3 axis accelerometer, a separate recording accelerometer, on-board color video, and a spectrograph that will analyze the spectrum of the rocket plume. Positional data from the GPS system, accelerometers, and barometric altimeters can be compared to determine the exact flight characteristics and measure the accuracy and precision of the various sensors. A sophisticated three dimensional analysis of the rocket's motion will be developed.

The onboard spectrometer will yield spectral data from the hybrid rocket exhaust plume in flight. This data will be compared to spectral observations of static tests. Significant combustion intermediates will be identified in the spectra. Comparison of the static test firing rocket plume spectra and in-flight spectra will allow us to see whether acceleration during flight, airflow over the exhaust plume, or in flight turbulence has a significant effect on plume shape and combustion characteristics. Also, the in-flight video will allow for frame-by-frame analysis synchronized with the spectrometer and positional data to explain any in-flight anomalies, as well as providing an important promotional tool.

Spectral analysis of hybrid rocket plumes is a continuation of research already underway at Harding University. See the following representative publications:

1) *Ultraviolet-Visible Spectrometry Characterization of Combustion in Hybrid Rocket Motors.* E.

Wilson, B. Keller et al., American Institute of Aeronautics and Astronautics AAIA Paper 2006-4343, July 2006.

2) *OH Emission Spectra of Hybrid Rocket Motors Using PMMA and HTPB*, E. Wilson, J. Mackey, B.Keller et al., American Institute of Aeronautics and Astronautics AAIA Paper 2005-3905, June 2005.

Science Value

Analysis of hybrid rocket exhaust plumes via spectroscopy provides the following scientific value:

1) New sensors are developed that have multiple applications within rocketry and in other related fields
2) Combustion intermediates can be identified, spatially mapped, and quantified.
3) A clearer picture of the complex chemical reactions involved in rocket combustion can be arrived at by understanding combustion intermediates
4) Environmental of the rocket motor can be ascertained from the quantities of various pollutants emitted.
5) In-flight analysis allows for comparison with observations from static test firings, an evaluation of the effects of acceleration and air flow on hybrid rocket exhaust plumes. For example, does the presence of a tailcone effect airflow over the rocket exhaust plume in a way that maximizes potential thrust?

III) Activity Plan

October 7- Selected payload package
October 23- Teleconference-Proposal review
November 5- Designed the rocket
November 13- Order parts for payload, USLI rocket, scale test vehicle
December 15- Construction of rockets begins
December 22-29- Static testing of ejection systems
January 13- Scale test vehicle launch in Memphis
January- Outreach project, Elementary School project, Newspaper article to publicize project in community
January 20- Payload testing, integration of electronics with USLI rocket
February 10- USLI system flight test, half-altitude flight (2500 ft. target)
March- FDR, USLI system flight test; full-altitude flight (5280 ft. target)
April- Final flight light in Alabama or Tennessee
May- Final report

IV) Summary

The Harding University USLI Team, will thoroughly document the planning and construction of a rocket that will achieve an altitude of 5280 feet carrying a scientific payload, and safely recover the rocket in a reusable condition.

The rocket airframe will be 4” in diameter and approximately 9 feet long, featuring fiberglass reinforced phenolic tubing and a urethane tailcone. Clipped-delta G-10 fiberglass fins and the capability of using 54mm, 54mm Hammerhead, and 76 mm hybrid rocket motors, along with modular electronics bay units will make the test vehicle highly versatile.

The electronics payload will contain a flight computer with a 3-axis accelerometer, spectrograph, GPS board, and telemetry attachments, supplemented by two altimeters and a self-contained BoosterVision video camera with transmitter to comprise the payload. The predicted motor of choice is a Hypertek K240 hybrid.
Standard dual recovery will be used, with a drogue deploying at apogee and a main parachute deploying at 800 feet. Redundant electronics systems will deploy the main and drogue parachutes. Telemetry transmission will allow for the retention of scientific data and in-flight video in case the rocket is not recovered.

The onboard spectrometer will yield spectral data from the hybrid rocket exhaust plume in flight, and significant combustion intermediates will be identified in the spectra. The scientific payload will thus provide unique, creative insights into the hybrid rocket combustion process during a flight, as well as returning detailed positional data and video. Combined with the benefits of following a rigorous design, review, construction, and documentation process, the Harding USLI team members will gain much knowledge about systems engineering for NASA projects.