Harding University

University Student Launch Initiative

Critical Design Review

January 28, 2008

2006-07 Flying Bison Team

Harding University Flying Bison

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1. Technical Design

1.a. Projected general vehicle dimensions

The rocket airframe is designed to reach the target altitude of one mile given the 54mm propulsion system described in Section 1.b. The airframe will be 94” (2.39 meters) long with a 3.1” diameter and is divided into three components. The aft section (to which the fins are attached) houses the 36” long 54mm motor mount tube. The fins attached to this section are composed of two layers of 1/8 inch 3-ply birch plywood, with layers of fiberglass and carbon fiber in between (see Appendix I, Figures A-2 – A-4). The middle section (20” in length) holds the recovery electronics (forward) and the scientific payload (aft). The 10” forward portion of this middle electronics section utilizes a core electronics support structure surrounded by removable, transparent acrylic tubing to maximize the visualization of and access to the electronics. The forward body section (28” in length) houses the drogue parachute, main parachute, Chute Tamer deployment device, and various recovery hardware such as the tubular nylon shock cord and Nomex parachute protectors.

The Chute Tamer device (available through LOC/Precision at http://www.chutetamer.com/) binds the main parachute so that it may be deployed with the drogue parachute at apogee without unfurling. The Chute Tamer has a programmable timer, allowing one to select a desired delay before main parachute deployment. At the appropriate time, a heating element in the Chute Tamer cuts a wire holding the main parachute in place, allowing it to deploy fully. This configuration is necessary for a one-electronics-bay dual deployment design because the electronics bay must be attached permanently to the aft section so that a fiber optic cable can run from the nozzle of the hybrid rocket motor to the spectrometer.

Figure 1. Chute Tamer

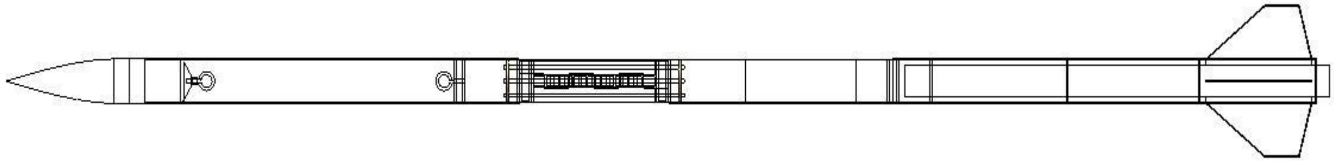

Figure 2. Side View Drawing of Rocket-Generated in SolidWorks 2007

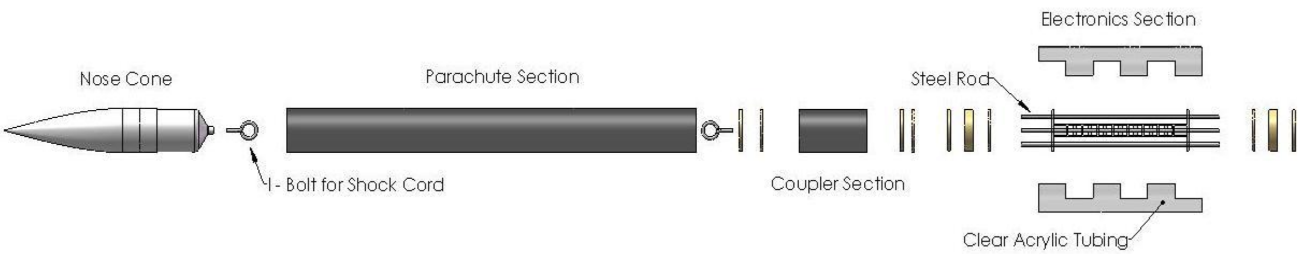

Figure 3. 3-D Rendering of Fore Section of Rocket--Generated in SolidWorks 2007

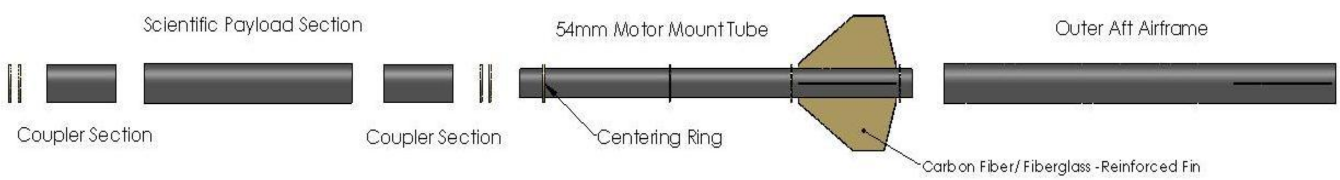

Figure 4. 3-D Rendering of Fore Section of Rocket -Generated in SolidWorks 2007

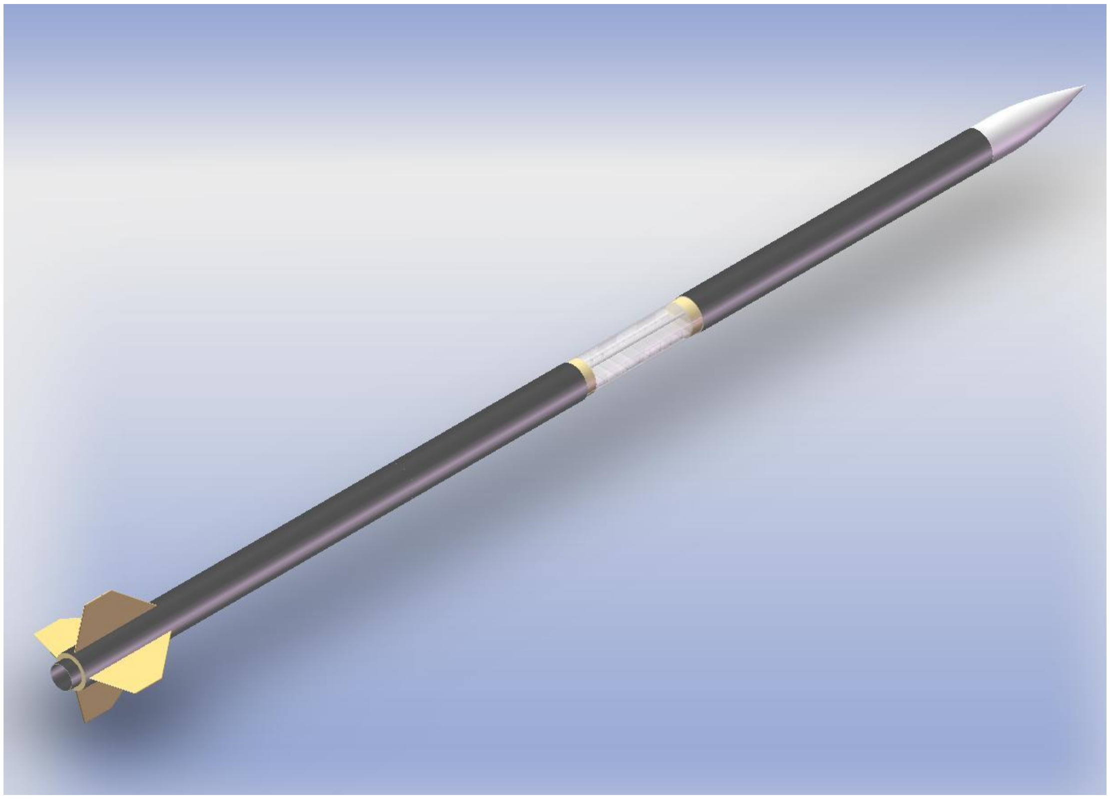

Figure 5. 3-D Isometric Rendering of Rocket-Generated in SolidWorks 2007

1.b. Project motor type and size

During last year's competition, the Flying Bison were successful in filling and lighting a Contrail Rockets 54mm K-class hybrid motor. A failure to develop proper launch procedures resulted in the premature venting of some of the oxidizer. This suboptimal oxidizer level, combined with a design already overly large and heavy for the target flight profile, prevented the 2006-07 flight vehicle from reaching the desired altitude of 5280 feet.

The 2007-08 flight vehicle will again fly with a Contrail Rockets 54mm hybrid motor. However, the Flying Bison will use a 54mm J-234 (total impulse of 1033 Newton-seconds) as the motor of choice, putting current simulations well over the mile mark. Using past experience, the Harding team knows that rockets tend to be heavier than Rocksim projections indicate, so designing the rocket to use larger motors is necessary. The flight profile may be refined after construction is complete and test flights have verified computer simulations by the addition of ballast to the rocket vehicle.

Motors in the J-L class require Level 2 certification (held by the safety officer) will be used, but the lack of ammonium perchlorate in Contrail Rockets hybrid motors precludes the need for an ATF Low Explosive Users Permit.

1.c. Project science payload and electronics

Electronics included within the rocket for data collection and interfacing during the flight will include a Perfectflite MAWD logging altimeter unit to record the official altitude of the competition flight and to deploy parachutes. A Boostervision wireless color 2.4Ghz Wireless Micro Camera will record in-flight video.

The scientific payload, located below the electronics section, will interface with an R-DAS flight computer for recording of measurements and transmission of telemetry. The RDAS unit will also act as a backup for parachute deployment and data logging, as well as allow the addition of features such as logging GPS coordinates. The RDAS flight computer will store information from a spectrometer, the specific science payload of the rocket, in order to measure the hydroxyl levels in the exhaust. Other modular units of the R-DAS flight computer include a 2-axisaccelerometer and pressure sensor, a GPS board, and telemetry transmitting and receiving capabilities.

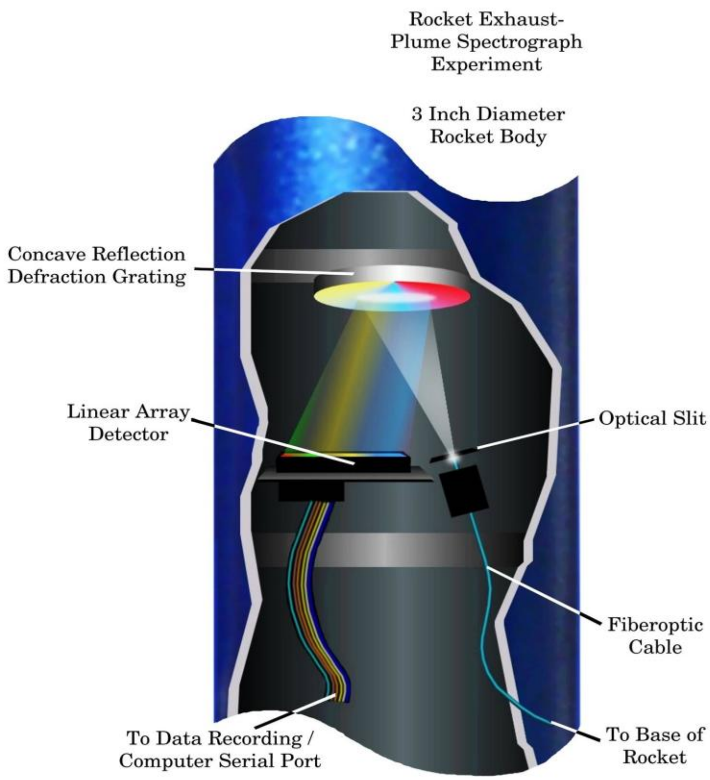

Figure 4. Cutaway diagram of custom-built spectrometer in avionics bay.

The primary original experiment flown in this rocket is the spectrometer for study of the hybrid rocket exhaust plume. Last year the Harding USLI team attempted to fly a photodiode to measure the intensity of the exhaust plume. Measurements were successful in static tests, though not in the competition flight, likely due to wiring coming loose. The spectrometer being developed for the 2007-08 competition rocket is based on a SpectraWiz compact spectrometer.

Positional data from the GPS system (allowing in-flight tracking of the rocket), 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 can be developed from this data.

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 such as hydroxyl radical 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 in the form of on-board video.

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.

1.d. Primary requirements for rocket and payload

The first goal for this project is to build a rocket capable of reaching the desired altitude of 5280 feet and capable of being reasonably retrieved via dual deployment recovery techniques. The second goal is to build a working science package including a spectrometer that can be used to analyze the plume gradients; this spectrometer will be mounted in conjunction with the R-DAS flight computer and secondary scientific instruments associated with the R-DAS for storage of data and real-time transmission to the ground. If these requirements are met, then this project will be a success.

1.e. Major challenges and solutions.

We expect to encounter several major challenges during the course of this project. Ignition of non-pyrotechnic hybrid rocket motors such as Contrail Rockets Hybrids requires the use of relatively complex ground support equipment and flight procedures. The airframe of the rocket will encounter considerable stress and must be designed to avoid premature separation, fin flutter, or zippering upon recovery system deployment. Variable thrusting characteristics of hybrid rocket motors may necessitate lock-out intervals for recovery devices including barometric altimeters. Recovery from high altitude is problematic in traditional rocketry designs, so dual deployment (using a drogue at apogee and main parachute after a set period of time) will be employed. Because hybrid motors carry no motor ejection charge for redundant deployment, a completely separate secondary electronic system (MAWD) will backup the primary (R-DAS) recovery system.

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 flight tests planned on March 8 and April 12 will allow the team to verify the performance of the rocket and adjust the overall weight so as to approach the target altitude of 5280 feet.

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 University has developed a static test facility for 29, 38, and 54mm 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. Contrail Rockets products were selected based on performance criteria and ease of use.

2. Outreach

The Harding University Flying Bison Team is engaged in numerous activities to educate the community, especially schoolchildren, about our activities and rocketry in general, as well as to foster beneficial relationships to lay a framework for future success. While current project expenses are being covered by indirect funds generated by a NASA/EPSCoR grant held by Dr. Ed Wilson, Team Official, a proposal is being generated for additional funding from the Arkansas Space Grant Consortium, which fully sponsored the 2006-07 Flying Bison team.

Searcy's *Daily Citizen* newspaper featured the Flying Bison in the Saturday, January 26 2008 edition. The article entitled "Sky rockets in flight," detailed Harding's participation in the University Student Launch Initiative.

Harding University and The Flying Bison were also featured on Channel 7's *Good Morning Arkansas*. Megan Bush, a member of the team, was interviewed on the Little Rock morning show. Megan explained the underlying concept of the USLI competition and the role of the Flying Bison Team to a live studio audience and a cable TV audience throughout the state. She had the opportunity to talk about the USLI competition and the grants that Harding has received in order to continue research on hybrid rocket motors. A video of the interview is posted on the team's website.

Project Leader Brett Keller presented a poster detailing the rocket team and the competition at the Arkansas INBRE research conference at the University of Arkansas on November 10. Brett's poster focused on the scientific payload being constructed by the Flying Bison team and on the ways in which scientists may work with hobbyists to best utilize available technologies. Brett's poster won second place in the physics division of the poster competition. Brett was subsequently featured in an article in *The Daily Citizen*. The article is also posted on the team's website.

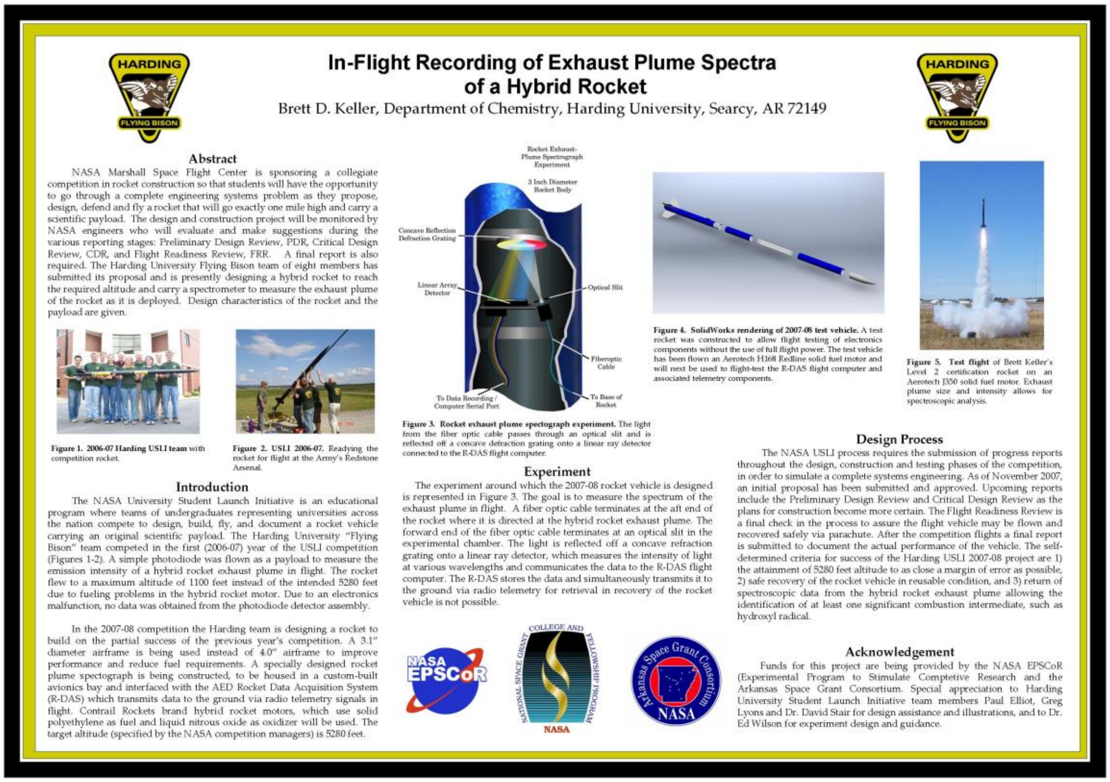

Figure 5. Poster presented by Brett Keller at Arkansas INBRE scientific conference on the USLI competition. Keller's poster won 2nd place in the physics division.

Team members are also developing plans to present educational material on science and model rocketry to Searcy area schoolchildren under the direction of Megan Bush, outreach coordinator for the Flying Bison. The team will assist classes in preparing and flying small water bottle rockets and demonstrate model rocketry. Information about the USLI competition and the ways in which science and engineering can be applied to rocketry will be presented in an appropriate format.

Additional media coverage is pending in the *Arkansas Democrat Gazette*, Arkansas' daily newspaper with the highest circulation. Press releases on future events—from outreach activities at schools to the USLI competition flights—will be distributed to local media outlets and posted on the USLI website.

3. Project plan

The Flying Bison are on schedule to test launch in Memphis on February 9, 2008. The team is ahead of schedule and has completed most of the physical construction (see Appendix 1, Figure A-1). The Arkansas Space Grant Consortium is also funding the construction of the rocket and travel to the 2008 launch.

3.a. Timeline

The Harding USLI team is currently on-schedule. Major construction of the rocket airframe and electronics section will be completed by early February, and the scientific payload and other electronics should be completed by mid to late February in preparation for the March 8 test flight.

January 28: Critical Design Review Presentation Slides and CDR Report due
January: Bench testing of spectrometer with R-DAS and other electronics components
February 2: Static test of hybrid motor and spectrometer
February 4: Critical Design Review (tentative)
February 9: Memphis launch; test fly Perfectflite MAWD in Dr. Wilson's Level 1 rocket with hybrid I motor.
February: Complete airframe construction of competition vehicle
March 8: Memphis launch: test flight of competition vehicle on hybrid I motor
March 31: Flight Readiness Review Presentation Slides and FRR Report due
April 7: Flight Readiness Review (tentative)
April 12: Memphis launch: test flight of competition vehicle on J-234 hybrid motor (full power, full scale test flight)
April 18: Flight Hardware Check (tentative)
April 19: Launch Day (Rain date of April 20)
May 12: Post-Launch Assessment Review

3.b. Projected Budget

The source of the required funds is from indirect funds generated by a NASA/EPSCoR grant held by Dr. Ed Wilson, Team Leader. The Arkansas Space Grant Consortium has provided more funds for the Harding 07-08 Flying Bison team. Grant number SWI7929 entitled "Harding University Flying Bison USLI Rocket Competition" is fully funding the USLI competition rocket.

Expense	**Amount**
1. Rocket Airframe Construction	150.00
2. Payload and recovery:	
Perfect Flight MAWD	100.00
Parachutes and Recovery Harness	100.00
Spectrometer and payload components	150.00
ChuteTamer parachute deployment device	200.00
5. Contrail Rockets J Motor system and reloads	300.00
7. Safety and L1 & L2 Licensure	50.00
8. Outreach	50.00
Estimated total	**1000.00**

Hybrid ground support equipment, R-DAS flight computer (with GPS, accelerometer, and telemetry boards), G-Wiz altimeter, fiberglass and carbon fiber cloth, and West Systems epoxy are already available to the USLI team.

4. Safety and Environment

4.a. Safety Officer

Brett Keller, NAR #86412, L2 certified

4.b. Analysis of failure modes

The risks to the successful deployment of our recovery system are as follows:

Recovery failure under thrust (premature deployment)

Probability: Probability is low

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.

Impact: Negatively altered flight path, extra stress on frame and parachute attachment scheme

Risk mitigation: Mach-inhibition on barometric deployment devices, vent holes in parachute sections, multiple vent holes of sufficient size in recovery electronics section.

Airframe damage on parachute deployment

Probability: Probability is low

Possible causes: poor airframe design or insufficient strength.

Impact: zippering, collision

Risk mitigation: anti-zipper design of booster section, reinforced airframe.

The failures that could potentially inhibit the successful deployment of our recovery system are as follows:

Failure to deploy either parachute

Possible causes: Complete failure of electronics, failure to fire ejection charges, insufficient ejection charge size.

Potential effects of failure: ballistic reentry, complete loss of rocket body and electronics

Failure prevention: 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 using an I hybrid motor.

Partial deployment of recovery system

Possible causes: incorrect parachute and recovery harness packing, failure of main parachute to deploy after drogue deployment (Chute Tamer malfunction).

Potential effects of failure: Rapid descent of rocket under drogue only would lead to high impact speed and greater probability of airframe damage.

Failure prevention: practice parachute packing techniques and Chute

Tamer procedures, test fly Chute Tamer device with dual recovery in other rockets.

4.c. 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.

4.d. 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.

5. Summary

The Harding University USLI Team, the Flying Bison, will thoroughly document design, construction, testing, and flight of a rocket that will carry a scientific payload, and safely recover the rocket in a reusable condition. The rocket airframe will be 3" in diameter and approximately 9 feet long, featuring fiberglass reinforced tubing and a clear electronics bay. 54mm hybrid motors, such as the Contrail Rockets J-234, will carry the rocket to a projected altitude of 5280 feet. The electronics payload will contain a flight computer with a 3-axis accelerometer, spectrometer, GPS board, and telemetry attachments, supplemented by the competition altimeter and a self-contained BoosterVision video camera with transmitter to comprise the payload.

The airframe will separate at apogee, releasing a small drogue parachute and the main parachute bound by the Chute Tamer device. After a programmed length of time, the Chute Tamer will release the main parachute, allowing the USLI competition rocket to benefit from standard dual recovery while eliminating the complexity of multiple electronics bays and ejection charges. Redundant electronics systems will deploy the main and drogue parachutes. Telemetry transmission will retain 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 2007-08 team members will gain much knowledge about systems engineering for NASA projects.

Appendix I.

Figure A-1. Major structural components of the competition rocket: (left to right) 38 mm motor adaptor tube, five 3" coupler tubes, the three 34" long 3" diameter main body tubes in varying degrees of finish, and the 34" long 54mm diameter motor mount tube.

Figure A-2. Aaron Howell (left) and Paul Elliot apply West System epoxy to the fins during the composite fin layup.

Figure A-3. Greg Lyons uses a belt sander to round the edges of the fins.

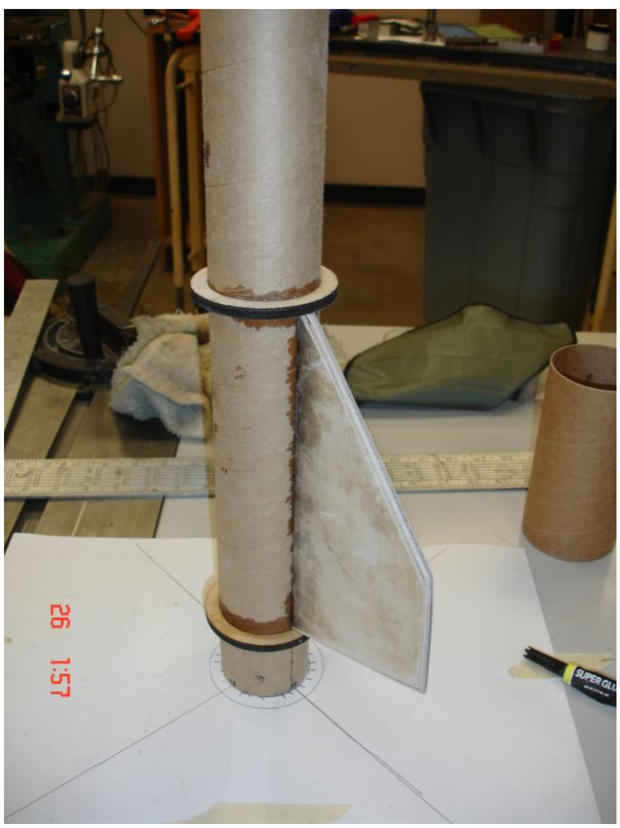

Figure A-4. The fins were attached to the motor mount tube with super glue before being reinforced with epoxy and carbon fiber.

Figure A-5. Carbon fiber was applied from fin to fin across the motor mount tube to make a strong fin can assembly.

Figure A-6. The slots in the tube are widened and lengthened to accommodate the reinforced fins.

Figure A-7. The outer (3" diameter) clear acrylic tubing with the electronics support board assembly that is housed within in. A 9 volt battery is installed in one of eight battery slots between the two support boards to which the electronics will be attached.

Figure A-8. The clear acrylic electronics support board installed in the 3" diameter clear acrylic tubing. One 9 volt battery is installed in a battery slot between the electronics support board mounting areas.