Harding University

University Student Launch Initiative

Flight Readiness Review

March 26, 2007

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Fig. 1. Harding's University Student Launch Initiative Team, posing with a launch vehicle developed for hybrid rocket flights in the summer of 2006.

Fig. 2. The logo for Harding's University Student Launch Initiative Team, "The Flying Bison."

I. Vehicle Criteria

I.A. Testing and Design of Vehicle

Harding's University Student Launch Initiative, the "Flying Bison" is still undergoing construction. When complete, it will be 4.02" (102.11mm) in diameter, 8'9" (2.684 meters) long, and weigh an estimated 12.2 lbs (5.53 kg). With a full 48" long 54mm motor mount, the Flying Bison is capable of flights on I, J, and K hybrid rocket motors, including those manufactured by Contrail Rockets.

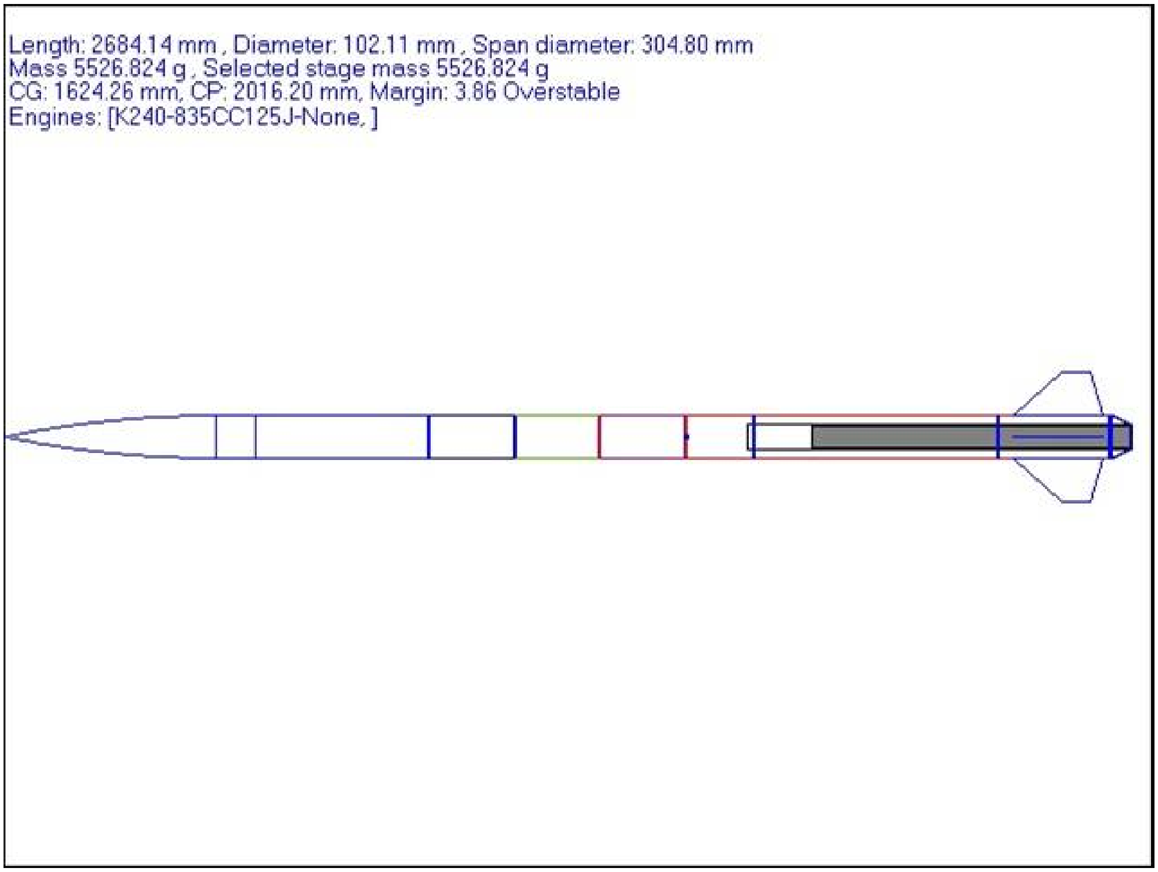

Fig. 3. Simplified Rocksim schematic of the Flying Bison. Left to Right: Nose cone, main parachute bay, forward electronics bay, drogue parachute, aft electronics bay, motor mount & fin can

I.A.1. Use of materials

Materials are selected by three main criteria: strength, weight, and cost. Large metal components were avoided and composite layups were widely used. Specific materials and dimensions used are:

•Airframe is 3.9" diameter flexible phenolic tubing from Giant Leap Rocketry.

•Airframe reinforced with one layer of Kevlar sock, one layer 6 oz. fiberglass, and one layer 2 oz. veil cloth (for finishing purposes).

•Lower (booster) airframe is 48" long (to accommodate Contrail 54mm K hybrids)

•Upper (payload) airframe is 42" long.

•Main airframe tubing reinforced with Giant Leap Rocketry Kevlar sock, 2 layers of 6 oz. fiberglass, and 2 oz. fiberglass veil.
•Fins reinforced with 6 oz. fiberglass and 2 oz. fiberglass veil. Motor tube to fin tab joints reinforced with carbon fiber.
•Interior of coupler tubes reinforced with 6 oz. fiberglass cloth.
•Motor mount is a single 36” 54mm flexible phenolic tube mounted.
•Motor mount tube is mounted in body tube with 3 3/16” thick birch centering rings, one on forward and aft edges of fin tabs, creating a “fin can,” and one at the forward end of motor mount tube.
•Tail of rocket features 98mm-54mm Slimline Tailcone Retainer: black anodized aluminum cone reduces drag and secures motor during ejection.
•Fins are 5’16” plywood, laminated with 6 oz. fiberglass on each side and 2 oz. veil cloth
•4” span, 7” root, 3” tip swept delta configuration
•4 fins with through-the-wall mounting, attached to 54mm motor mount tube with carbon fiber and to outer body tube with 6 oz. and 2 oz. fiberglass fillets.
•Fin alignment via a custom cut wood alignment jig to be built in our machine shop to ensure proper alignment.
•Nose cone is a Giant Leap Rocketry 3.9” Pinnacle plastic ogive nosecone
•18.5” in exposed length (5 to 1 length to diameter ratio), 5.75” shoulder
•Parachute harness mounted with 3/8” eyebolt installed in base of nose cone
•Nylon rail buttons (compatible with BlackSky and Extreme rail systems) installed midway between two fins, at rear and top of booster body tube section
•Two 6’ sections of rail recommended for flight operations

I.A.2. Alignment, strength of assembly/attachment

•All major airframe components are reinforced as listed above. Connection between airframe components uses West Systems epoxy. In addition, the following joints are reinforced as follows:
•Load-bearing tube couplers have an internal wrap of 6 oz. fiberglass.
•Fin-to-motor-mount joints are reinforced with carbon fiber and epoxy.
•Fin-to-body-tube joints are reinforced with 6. oz. and 2. oz. fiberglass and epoxy.
•Fin alignment is accomplished with a custom wood jig built in our shop. The jig holds the 4 main fins in place for attachment to the motor mount tube, and also provides alignment information for marking the main tube for fin slotting and rail button attachment.
•Recovery Connection points: Attachment of the main and drogue parachutes to the nose cone and various bulkheads is accomplished with 3/8” (welded, closed-eye) eyebolts. All uses of bolts and threaded rod in the avionics bays use 3/8” all-thread with nuts, lock-washers, and washers to distribute the loads applied.

I.A.3. Motor mounting and retention

48" long 54mm motors are accommodated by the motor mount. The motor mount tube is 36" long 54mm Giant Leap Rocketry phenolic tubing. The upper 12" of a 48" motor extends beyond the top of the motor mount tube into a void in the top of the booster section, below the aft (lower) avionics bay housed in the tube coupler. A vent hole in the side of the main body section near the aft avionics bay allows for the passage of the filling vent tube on a Contrail Rockets hybrid motor. The motor mount tube is secured in the main airframe via three centering rings and composite-reinforced fin through-the-wall fin attachment, creating a reinforced "fin can" design.

The motor is prevented from moving forward by the integral thrust ring on its exterior, aft portion, common to solid-fuel reloadable rocket motors and hybrids alike. The motor is prevented from moving aft by the positive motor retention system integrated into the Giant Leap Rocketry Tailcone. The rear of the tailcone has a series of threads in which threaded inserts engage to ensure motor retention.

Fig. 4. Giant Leap Rocketry 98mm to 54mm black anodized tail cone.

I.A.4. Approach to workmanship

All parts will be manufactured and assembled by multiple team members. Shop equipment will only be used under the supervision of members with experience. All mission-critical assembly steps (load bearing joints, recovery subsystem testing and assembly) will be supervised by the Safety Officer, a L2 certified rocketeer.

On internal surfaces epoxy joints are kept neat to minimize use of epoxy due to weight considerations, and to allow for proper mounting of electronic components.

While the appearance of the Flying Bison is not vital for flight success, it is indicative of overall workmanship and helpful in publicity, so an excellent finish is desired. All exterior surfaces will be sanded and filled with Elmer's wood-filler and/or Bondo to provide a uniformly smooth surface. Fiberglass-reinforced section will not be sanded past the outer veil (2 oz.) layer. Final finishing will be accomplished via spray primer and paint, alternating with sanding.

Ventilator masks and gloves will be used during all sanding, painting, or cleaning that involves dust products from the rocket.

I.A.5. Safety and failure analysis

Failure mode	**Cause**	**Effect**	**Risk mitigation**
Motor CATO or chuff	Manufacturer's defect or faulty assembly	Severe damage to rocket, possible harm to bystanders if rocket leaves launch pad under insufficient thrust for stable flight	Practice motor assembly and nitrous loading, follow all instructions, and static fire hybrid motor on test stand to assist in development of checklists to minimize the possibility of failure.
Structural failure under thrust (shred)	Major structural failure, fin flutter, body tube crimping, coupler failure	Severe damage or complete destruction of flight vehicle	Through-the-wall fin mounting, composite reinforcement of tubes, fins, couplers, 1.5 body-caliber coupler insertions.

I.B. Recovery Subsystem

I.B.1. Parachute attachment, deployment, and ejection

Overview of parachute deployment mechanism:

Drogue parachute deployment is initiated by apogee detection by redundant barometric altimeters (R-DAS flight computer and PerfectFlite altimeter) and an accelerometer (G-Wiz MC 2.0). The G-Wiz MC 2.0 and PerfectFlite altimeter, housed in the forward electronics bay, will be wired to separate flashbulbs in the same black powder charge. The R-DAS flight computer, housed in the aft electronics bay, will be wired to an independent flash bulb and black powder charge. Either charge will be sufficient to separate the rocket and initiate drogue deployment. Charge size will be determined by static testing. External key switches controlling the power supply to each of the three deployment electronics can be used to disarm the explosive charges without dismantling the rocket.

Main parachute deployment at 800 feet is controlled by the electronics of the forward electronics bay, the PerfectFlite and G-Wiz MC 2.0, each of which will be wired to a separate flashbulb and separate black powder charges. Either can independently ejecting the nose cone and parachute. The likelihood of both methods detecting 800 feet and firing ejection charges simultaneously is minimal. Subsequent firing of both charges will increase the likelihood of full ejection of the recovery harness.

Parachute bays and mounting:

•Drogue (aft) parachute bay- allows 4” diameter x 8” space for parachute and harness plus 5” shoulder for booster section coupler/bulkhead assembly (which houses aft electronics bay) and 5” shoulder for upper electronics bay (housed between the drogue and main parachute bays).

•24” Sperachute drogue parachute (with attached swivel), 30 feet 1” tubular nylon parachute harness.

• 30” Kevlar sleeve for tubular nylon recovery harness, Kevlar parachute protectors to prevent ejection charge damage.

•Climbing-rated carabiners for all parachute harness to hardware connections

•2 nylon sheer pins on booster section coupler. Configuration will be ground-tested with ejection charges to assure sufficient charge size for separation.

• Main (forward) parachute bay- allows 4” diameter x 16” space for parachute and harness plus 5” shoulder for top of upper electronics bay and 5.85” for nose cone shoulder.

• Main parachute selection will not be finalized until final dry weight is known. Likely parachute is Size 72 Tac-1 main parachute (17 fps descent rate with 15 lbs). 30 feet 1” tubular nylon parachute harness.

• 30” Kevlar sleeve for tubular nylon recovery harness, Kevlar parachute protectors to prevent ejection charge damage. Climbing-rated carabiners for all parachute harness to hardware connections. 2-4 nylon sheer pins on booster section coupler.

Figure 5. Giant Leap stock photo of TAC-1 parachute

I.B.2. Safety and failure analysis.

Failure mode	Cause	Effect	Risk mitigation
Recovery failure under thrust (premature deployment)	Early ejection firing due to discontinuous airflow or electronic malfunction	Severe or complete destruction of flight vehicle	Drill properly spaced and sized airframe venting holes, develop checklist for proper installment of electronics, test on smaller scale rocket with motor ejection charge backup.
Recovery failure during coast (premature separation)	Friction fit on couplers too lose	Damage to recovery system, zippering of tubes	Use shear pins on all recovery separation points, test ejection charges to verify strength is sufficient to break shear pins
Partial deployment of recovery system	Incorrect parachute/ recovery harness packing, failure of main chute to deploy after drogue	Recovery may be faster than desired due to tangling of parachutes and harness	Pack chutes loosely and in proper order to avoid tangling. Use vigorous drogue ejection charges.
Airframe damage on parachute deployment (zippering, collision)	Poor airframe design, insufficient strength of materials	Damage to tubing, recovery harness	Anti-zipper design of booster section, proper sizing of ejection charges to prevent excess speed, long recovery harness
Deployment of main and drogue parachutes at apogee	Insufficient friction fit on main parachute separation point coupler	Long drift, difficulty in retrieving rocket	Shear-pins on main main parachute separation point coupler, ground testing of ejection charges with shear pins
Failure to deploy either parachute (ballistic reentry)	Complete failure of electronics, failure to fire ejection charges, insufficient ejection charge size	Complete destruction of launch vehicle. Possible property or bodily injury.	Multiply redundant electronic recovery systems, independent power supplies, and independent ejection charges. Pre-flight testing of electronics and ejection charges, and familiarity-

			building flights with smaller scale rocket with motor ejection charge backup.

I.C. Mission Performance Predictions

I.C.1. Mission performance criteria

•Successful completion of USLI design process (Proposal, PDR, CDR, Final Report).
•Constructing and testing vehicle airframe, recovery system and payload.
•Safe ascent of vehicle and recovery of all components in reusable condition.
•Achievement of 5280 feet altitude within 5%.
•Return, via telemetry and post-flight downlink, of the following data: altitude, 3-axis acceleration, GPS, temperature, pressure, color video with sound, and spectroscopic analysis of exhaust plume (to be compared with results from ground tests).

I.C.2. Simulations

Rocksim data for Contrail Rockets 54mm K motors is not available. Accurate performance predictions will not be available until flight testing occurs prior to competition launch. Final component weights will be used in Rocksim simulations after flight vehicle construction is complete.

Primary motor:
Contrail Rockets 54mm K321 (total thrust 1570 Ns- 22 % K) 4.89 sec burn

Similar simulations:
Aerotech J390HW (1280 Ns) 5393 feet
Aerotech K485 (1686 Ns) 7188 feet

I.D. Safety and Environment

I.D.1. Safety Officer

Brett Keller, NAR # 86412, L2 certified

I.D.2. Failure modes and mitigations

See sections I.A.5 and I.B.2 for detailed analysis.

I.D.3. 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
•Use of West Systems epoxy, fiberglass, and other adhesives requires gloves and respirators. Inhalation of dust produced by sanding and painting should be avoided by the use of respirators and good ventilation.
•Flight operations hazards 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.

I.D.4. 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.

I.E. Payload Integration

I.E.1. Integration plan

The scientific payload is integrated with the recovery electronics in the aft (lower) avionics bay. The wiring for the plume emission monitor will pass aft from the aft avionics bay toward the exhaust plume through the airframe, passing through the centering rings via a 3/8" inside diameter conduit next to the outer body tube. The plume emission monitor will terminate in the R-DAS unit for digitization and transmission to the ground for analysis.

I.E.2. Payload housing integrity

The plume emission monitor connects to the R-DAS unit, which is mounted to an electronics board within the lower (aft) avionics bay. The main board is mounted by cardboard launch lugs onto ¼" metal threaded rod, allowing the entire board to be removed from the avionics bay for mounting of components and preparation procedures. The avionics bay are as follows:
•Aft (booster section) electronics bay is housed in an 9" long B-3.9 coupler, bonded and bolted permanently to the booster section body tube and

extended forward as a 5” shoulder into the aft (drogue) parachute bay. (This forms a classic anti-zipper booster design.)

•The aft bulkhead is inset 2” from the aft end of the coupler to allow full insertion of a 48” long motor into the booster section, leaving 4” diameter x 7” of usable space for electronics.

•The forward and aft bulkheads are secured to each other via two 3/8” all-threads, nuts, washers, and lock washers. The electronics package is mounted on both sides of a removable 3.9” x 7” birch plywood sheet with 3/8” mounts on the all-thread.

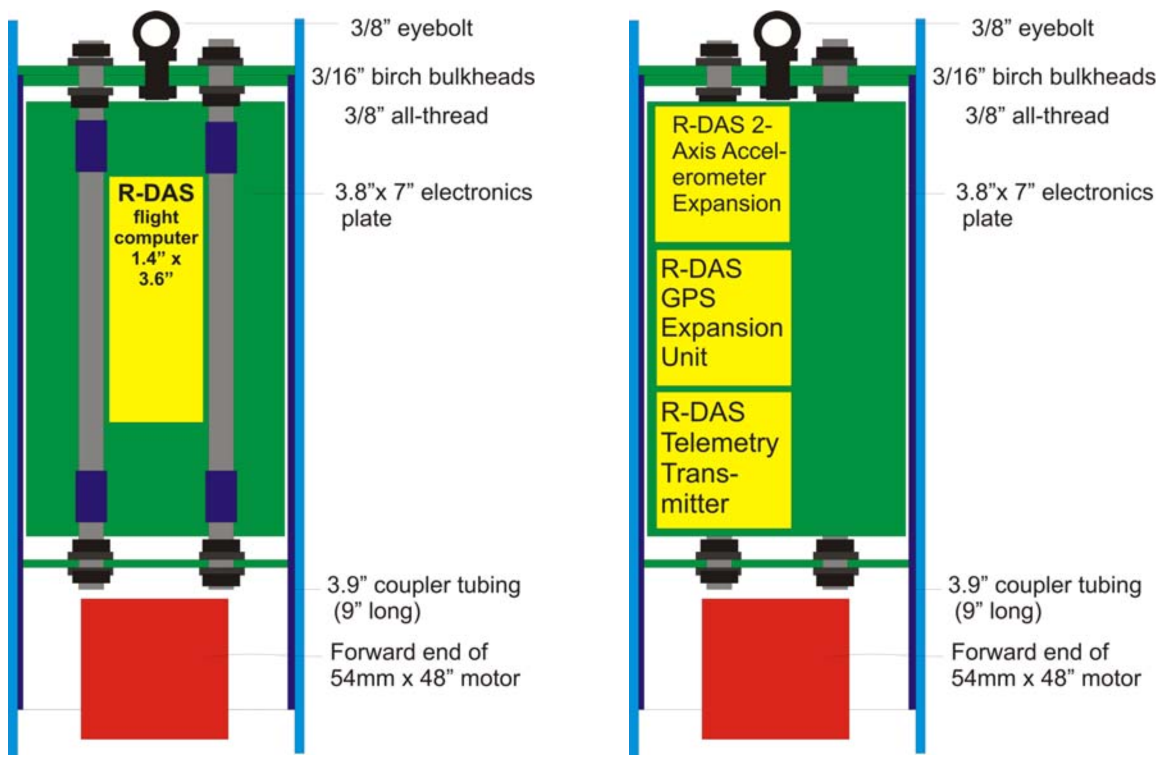

Figure 6. Diagram of bottom (left) and top (right) views of the electronics board in the aft (lower) avionics bay, housed in the coupler at the top of the booster section. The remaining empty (green) spaces can be used for mounting of batteries as well as tying down loose wires, such as those leading aft for the plume emission monitor.

II. Payload Criteria

Construction of the plume emission monitor and integration with the R-DAS flight computer is ongoing. Experimental procedures have not yet been developed as the method of integration into the R-DAS digital port and the conversion of data for telemetry transmission are being developed.

II.A. Experiment Concept

The payload designed for our rocket is unique enough to present a challenge while being achievable. Most of our sensors and actuators come pre-integrated with software so that their deployment will pose little difficulty. However, the goal of including a spectroscopic plume sampler aboard the rocket will increase difficulty to a point where our team must stretch our technical skills. Software will have to be developed to accomplish handshaking between the R-DAS flight computer and the spectroscopic plume sampler. We will also have to take the electrical signals generated by the optical plume sampler, amplify, condition, filter and convert them to levels appropriate for analog to digital conversion in the R-DAS computer.

Software will have to be created to convert the digitized signals, recorded sequentially at high speed during the burn time of the rocket flight, into a series of intensities. This will be quite demanding, but will definitely allow us to apply our software and hardware knowledge. The spectrum obtained by the spectroscopic plume sampler will cover the range of 300 to 1100 nm. Our plume emission measurements will provide a history of the rocket motor burn.

II.B. Science Value

II.B.1. Mission success criteria

See section I.C.1.

II.B.2. Experimental logic

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

- •New sensors are developed that have multiple applications within rocketry and in other related fields
- •Chronological history of the rocket motor firing from ignition to burn out
- •Clearer picture of the efficiency of combustion as the flight proceeds

•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 tail cone effect airflow over the rocket exhaust plume increase or decrease thrust?

II.C. Assembly
II.C.1. Integration and compatibility simplicity

Payload integration of the electronics will be simplified by the use of a flight computer with pre-made extensions. We will be using the standard R-DAS flight computer which has a built-in accelerometer and altimeter, along with the GPS module, 2-axis accelerometer and pressure sensor, and the telemetry transmission module, for receiving the data from our instruments during the flight.

The science payload presents the only significant obstacle to payload integration. A plume sampler will be connected to the R-DAS flight computer (in the aft electronics bay) via a fiber optic cable running internally (parallel to the motor mount tube) until it nears the rear of the rocket, where it will be mounted on the tail cone facing the plume. The plume sampler will integrate at the open digital data port on the R-DAS.

II.C.2. Structural integrity for flight

See Section I.E.2.

II.D. Safety and Environment
II.D.1. Safety Officer

Brett Keller, NAR # 86412, L2 certified

II.D.2. Failure modes

Failure mode	Cause	Effect	Risk mitigation
Plume emission monitor (PEM) fails to obtain emission data	R-DAS failure or failure with integration	Loss of potential data	Development of procedures for preparing PEM/ R-DAS combo for functioning by observation of hybrid static test firing
PEM data is unusable	Emission data from plume is indistinguishable from background noise.	Loss of potential data	Perform static test firings with PEM running in different light environments to establish

			baselines.

II.D.3. Personnel hazards

None due to plume emission monitor scientific payload.

II.D.4. Environmental concerns

None due to plume emission monitor scientific payload.

Fig. 7. Plume emission monitor with Silicon Photodiode and Amplifier and fiber optic cable terminated in with lens on each end.

III. Launch Operations Procedures

1) Assemble hybrid rocket motor (includes igniter- early ignition is not worrisome prior to nitrous filling) per manufacturer's instructions.
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 (R-DAS, Boostervision, G-Wiz, and PerfectFlite)
7) Ground support electronics and telemetry receivers tested for proper functioning (R-DAS and Boostervision)
8) External key 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, along with Kevlar parachute protectors
12) Airframe assembly/integration.
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, remove warning tags.
17) Verify proper signaling pattern on each electronics subsystem in turn.
18) Activate telemetry receivers and ground electronics. (If an electronics system is functioning unusually, power down electronics and ignition system, disassemble rocket and inspect)
19) Attach hybrid rocket fill tube.
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: motor hardware and retainer, fins, science payload fiber optic cable, recovery harness.
27) Process data stored on on-board electronics via computer downlinks.