CARBON-COPY

A LEVEL 3 HIGH POWER ROCKET PROJECT

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For:

National Association of Rocketry
Technical Advisory Panel

TABLE OF CONTENTS

CARBON-COPY

SECTION 1.0 – INTRODUCTION

The purpose of this paper is to describe the conceptualization, construction, and flight of an advanced high-power rocket. The overall goal of the project is to produce a Mach-capable, minimum diameter sport rocket capable of reaching very high altitudes (in excess of 20,000 feet) with very low probability of structural or recovery failure due to advanced design and generous use of advanced composite materials and adhesives. In addition, the design of the rocket allows the use of 38mm, 54mm, and 75mm AP motors, thus providing exceptional versatility in adapting to various launch conditions. The design also incorporates state-of-the-art flight control electronics to greatly decrease the probability of failed chute deployment. Lastly, to assist in the recovery of the rocket, a 219MHz electronic radio direction finder is incorporated in the nosecone.

Section 1.1 – General Description

Carbon-Copy is a minimum diameter, single-stage high-power rocket. The rocket has a 3.0 inch O.D., 2.88 inch I.D., and stands 91.0 inches tall. Approximate empty weight on the pad is 120 Oz. Estimated coefficient of drag at rest is .65 and at Mach 1 is .48. The static margin of stability with a loaded Aerotech 75mm casing and M1315 reload is approximately 1.03 caliber.

Section 1.2 – External Description

Externally, Carbon-Copy is composed of two 36-inch sections of 3.0 inch Performance Rocketry carbon fiber airframe tubing bonded together with one 7” section of Performance Rocketry carbon fiber coupler tubing using Aeropoxy high-strength structural paste adhesive. Three Alcoa T6061 0.125” fins provide aerodynamic stability. A Giant Leap Rocketry Slimline motor retainer is mounted on the aft end of the airframe. The fins are bonded to the airframe using extreme temperature resistant epoxy from Shadow Composites to withstand the temperature generated by the proximity of the reloadable motor. Dual laminations using 10.8 Oz. carbon fiber at the fin base provide additional strength and an aerodynamic fillet. A high-strength, 6-to-1 ogive carbon fiber nosecone from Performance Rocketry is mounted at the forward end of the airframe.

Section 1.3 – Internal Description

Internally, a 0.5-inch thick attachment bulkhead is mounted just below the airframe coupler tubing. The attachment bulkhead is made from multiple carbon fiber/balsa laminations. A fender washer is mounted on the aft side of the attachment bulkhead and a 1/16” aluminum plate is mounted on the fore side of the attachment bulkhead. An axially located 3/8” opening in the attachment bulkhead serves as the attachment point for the recovery module. This module consists of an altimeter bay located beneath a deployment bay. The ejection bulkhead, incorporated in the recovery module, is 1.00 inch thick and is constructed of plywood and composite laminations. A 3/8 inch stainless steel threaded rod is mounted through the ejection bulkhead and serves as the attachment point for the recovery harness at the top and the attachment bulkhead at the bottom. A PML coupler tube cut down to 28.25 inches is attached to the ejection bulkhead using Aeropoxy high strength structural adhesive.

The drogue parachute is a Rocketman ProXP R24D unit and the main parachute is a Rocketman ProXP R4C. The main recovery harness is made from seventeen feet of 5/8 inch tubular Kevlar. This harness attaches to the top of the 3/8 inch stainless steel rod with a marine grade stainless steel shackle rated to 1,300 pounds. The R4C is loop attached to the top of the main harness. Another six foot harness of 5/8 inch tubular Kevlar® attaches the R24D to the crown of R4C.

The altimeters bay houses a GWiz MC dual-deployment flight computer to control deployment of a drogue parachute at flight apogee and main parachutes at 800 feet. The MC is backed up by a G-Wiz LCD 800. Both units are mounted on a aluminum platform that slides onto the stainless steel all-thread rod. Power for the altimeters is supplied by four 9VDC batteries mounted in compartments inside the altimeter platform.

Also, a 219 Mhz Rocket Hunter radio transmitter is incorporated to assist with rocket recovery from extreme altitudes. The transmitter is located in the nosecone.

Section 1.4 Carbon-Copy Fact Sheet

Length	91.00 inches
External Diameter	3.00 inches
Internal Diameter	2.88 inches
Empty Weight	120 Oz.
Number of Fins	3
Fin Root Chord Length	9.00 inches
Fin Tip Chord Length	2.00 inches
Fin Span	4.00 inches
Fin Sweep	6.00 inches
Airframe Material	Carbon Fiber
Airframe Coupler Material	Carbon Fiber
Fin Material	Alcoa T6061 0.125" Aluminum
Motor Retention	Giant Leap Rocketry Slimline
Nosecone	Carbon Fiber Ogive 6:1 Ratio
Primary Altimeters	G-Wiz MC
Secondary Altimeters	G-Wiz LCD800
Drogue Parachute	Rocketman R24C
Main Parachute	Rocketman R4C
Planned Motor	Aerotech M1315W
Expected Altitude	20,000 AGL
Expected Maximum Mach	M1.8
Expected Maximum Acceleration	30g

Section 1.5 Recovery System Operation

Carbon-Copy uses dual deployment for parachute deployment. A GWiz MC flight computer and a GWiz LCD 800 control both apogee and low altitude deployment functions. At apogee, redundant charges inside the ejection tube pressurize the interior of the ejection tube and force out the drogue parachute, drogue harness, and nosecone. A retention harness attached to the top of the main parachute and anchored to a Blacksky ARRD prevents the main from deploying at apogee. Once the rocket descends to 800 AGL, redundant charges in the Blacksky ARRD fire and release the retention harness thus allowing the main parachute to be pulled free of the rocket.

Section 1.6 Unique Design Features

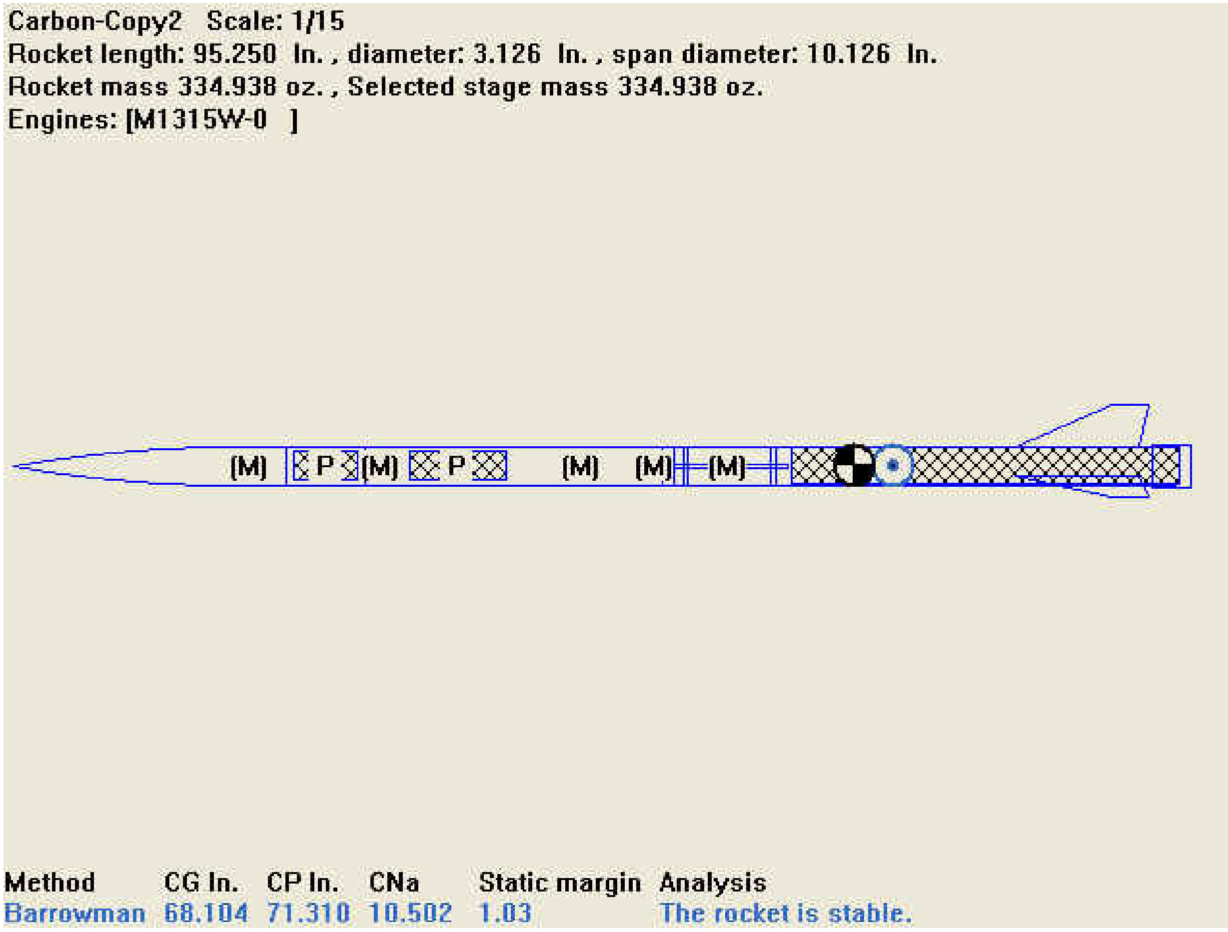
As stated above, Carbon-Copy utilizes dual deployment from a single opening. Use of this type of recovery system eliminates the airframe split point common in other dual deployment rockets and increases the structural integrity of the airframe, beneficial for Mach breaking flights. In addition, anchoring the main harness to an axially located all thread rod allows the Aerotech® 75mm casing to be threaded into the opposite end of the same rod. In this way, all recovery loads are distributed to multiple points in the airframe, including the motor casing, making it virtually impossible for a separation to occur. Furthermore, all three Kevlar® harnesses have ends that are through bolted and epoxied to minimize/eliminate the possibility of structural failure. Lastly, the altimeter platform is constructed in such a way as to incorporate battery compartments sized perfectly for 9V batteries. Once inserted, the batteries and their power connectors are locked in place and cannot move. This eliminates the possibility of the connectors coming loose under high acceleration and deceleration forces.

Section 1.7 – Design Concepts

The following details the major design concepts incorporated into Carbon-Copy.

Concept	Solution	Reason
Superior airframe integrity for Mach capable flight.	Elimination of airframe split point by use of the Blacksky ARRD. This allows drogue and main deployment from single opening at the forward end of airframe.	Deletion of airframe split point eliminates a failure point and thus decreases the probability of airframe failure particularly at high Mach numbers.
	All carbon fiber airframe.	Carbon fiber airframes are orders of magnitude stronger than there phenolic counterparts.
	Minimum diameter design	Aluminum motor casing provides superb structural integrity for lower half of airframe.
Robust recovery system incapable of failure even under extreme conditions.	Axially located stainless steel hardware for recovery system attachment.	Use of 3/8" threaded stainless steel rod for recovery system attachment to airframe provides superior integrity.
	Tubular Kevlar recovery harnesses with through-bolted aluminum and steel hardware for attachment loops.	Tubular Kevlar (5/8") is rated at 3,500 pounds thus providing the recovery system with extreme protection against failure.
	Parachutes from Rocketman constructed of heavy-duty rip-stop nylon and over-the-canopy tubular nylon shrouds.	Rocketman parachutes are generally regarded as the finest money can buy and, more importantly, the most rugged. Used exclusively for Shadow Composites extreme performance rockets.
	Attachment of forward closure on M motor casing to stainless steel recovery hardware.	Threading the forward closure into the aft end of the stainless steel attachment rod provides extreme failure resistance.
Exceptional fin attachment strength	Each fin is constructed of solid Alcoa T6061 0.125" thick aluminum	Aluminum has higher structural integrity than G10 and is not prone to cracking.
	Use of special structural epoxy with a glass transition temperature of 500 degrees Fahrenheit for main fin fillet.	Studies conducted by Tripoli indicate the external temperature of motor casings while operating exceed 200 degrees with potential for degraded epoxy integrity at fin/airframe joint.
	Multiple laminations of woven carbon fiber over main fin fillet for proper reinforcement of critical fin/airframe joint.	Encapsulation of main fin fillet with multiple (2) laminations of high-weight woven carbon fiber decreases probability of failure of fin/airframe joint.
Ease of flight preparation	Integrated recovery module allows preparation of all critical components outside rocket airframe	This design allows the user to check all critical components with superb access. Flight computers, batteries, harnesses, 'chutes, and deployment charges are all incorporated into one module that can be prepared prior to installation in the airframe.
Recovery of rocket after high altitude flight.	Incorporation of radio tracking device.	There is no point in building this type of rocket without guarantee of recovery after flight.

SECTION 2.0 – SCALE DRAWING



SECTION 3.0 – CONSTRUCTION DETAILS

The following sections describe in detail the construction of the various components of Carbon-Copy.

Section 3.1 – Attachment Bulkhead

The attachment bulkhead serves as a primary attachment point for the recovery system. Recovery forces for both drogue and main parachutes are largely directed into this one bulkhead. As such, the bulkhead was constructed using multiple laminations of 10.8 Oz. carbon fiber cloth and 1/32" balsa wood. The balsa was perforated using a special tool to create hundreds of tiny holes through the wood. These passages allow the laminating epoxy a means to travel through all carbon/balsa layers in order to form one integrated structure. Starting with the base lamination of carbon fiber, successive layers of balsa followed by carbon fiber were layed up. Each additional layer of carbon fiber was placed at a 45 degree offset from the previous lamination as were the balsa laminations. Aeropoxy laminating adhesive from Shadow Composites was used. After the layup was complete, the entire structure was placed underneath a fifty pound weight to squeeze out excess adhesive. After the epoxy had cured, a 3/8 inch hole was drilled in the center of the attachment bulkhead. A 3/8" fender washer was attached to the aft side of the bulkhead used stainless steel screws and epoxied into place. A 1/16" think aluminum plate was mounted on the forward side of the attachment bulkhead to complete construction of this component.

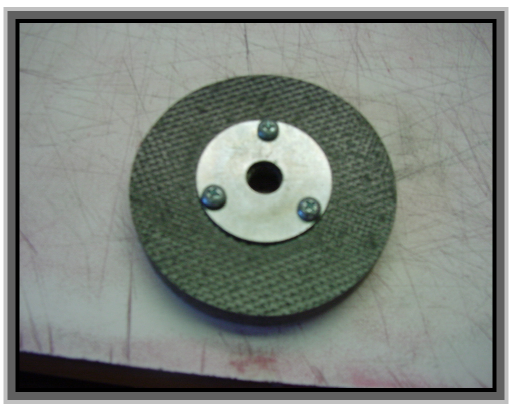


Plate #1 – Attachment Bulkhead

As can be seen in the photo to the left, the attachment bulkhead is of carbon fiber sandwich construction. The fender washer is attached via three screws to the bulkhead on the aft side of the plate. Screws were also epoxied into place. The forward bulkhead is drilled and chamfered to guide to stainless steel all-thread rod into the hole. The forward bulkhead also uses a final lamination of 1/16" thick aluminum.

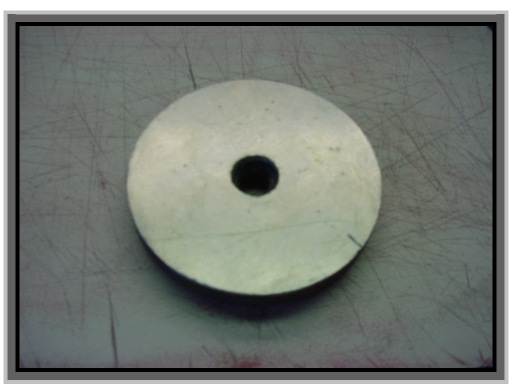


Plate #2 – Attachment Bulkhead

Attachment bulkhead as seen from the forward side. Aluminum lamination is bonded directly onto carbon lamination. Center hole is chamfered for accepting 3/8" all-thread rod.

Section 3.2 – Ejection Bulkhead

The ejection bulkhead is made from two ¼ inch thick birch plywood discs and two ¼ inch thick carbon/balsa laminated disks for a total thickness of 1 inch. A 3/8 inch diameter hole in the middle of the bulkhead allows the 3/8 inch all-thread rod to pass through the altimeter bay and the attachment bulkhead. The ejection bulkhead also serves as the attachment point for the Blacksky ARRD. The ejection bulkhead was drilled and countersunk for attachment of the ARRD. In addition, the ejection bulkhead was drilled for two conduits inside of the ejection tube. These conduits contain the following:

1. Drogue charge leads
2. ARRD charge leads

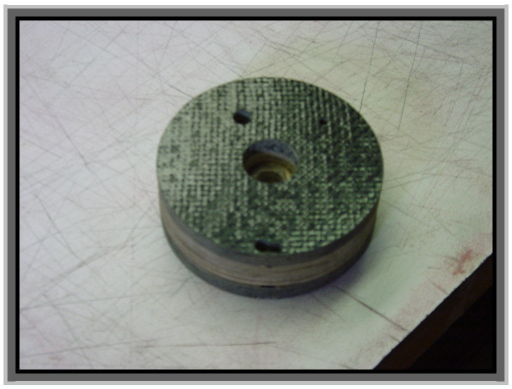


Plate #3 – Ejection Bulkhead

As shown in the photograph at left, the ejection bulkhead, forward side, is used to mount the Blacksky ARRD and stainless steel recovery rod. The small hole in the ejection bulkhead (as seen in the foreground) is for the drogue charge conduit. Center hole is for the 3/8" all-thread rod. Hole above and to the left of center hole is for mounting of ARRD. Small hole to the right and above of center hole is for ARRD charge leads.

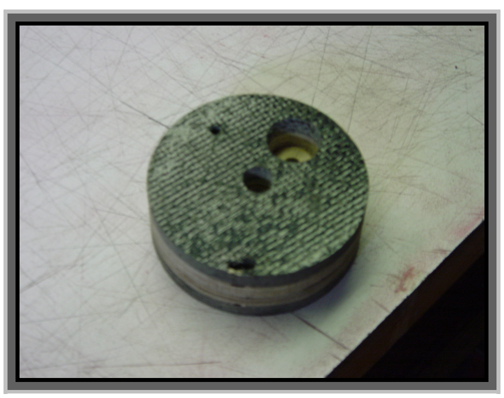


Plate #4 – Ejection Bulkhead

Same bulkhead, aft side view. As can be seen in this photograph, the mounting hole for the ARRD is expanded to accommodate the nut and locking washer.

Section 3.3 – Ejection Tube

The ejection tube is simply a PML 3" coupler tube 28.25 inches in length. An aluminum conduit for the drogue charge leads is attached to the interior wall of the ejection tube. The ejection bulkhead is mounted inside the aft end of the ejection tube using Aeropoxy structural adhesive. The combined ejection tube, altimeter platform, switch plate, and all thread rod form the recovery module.

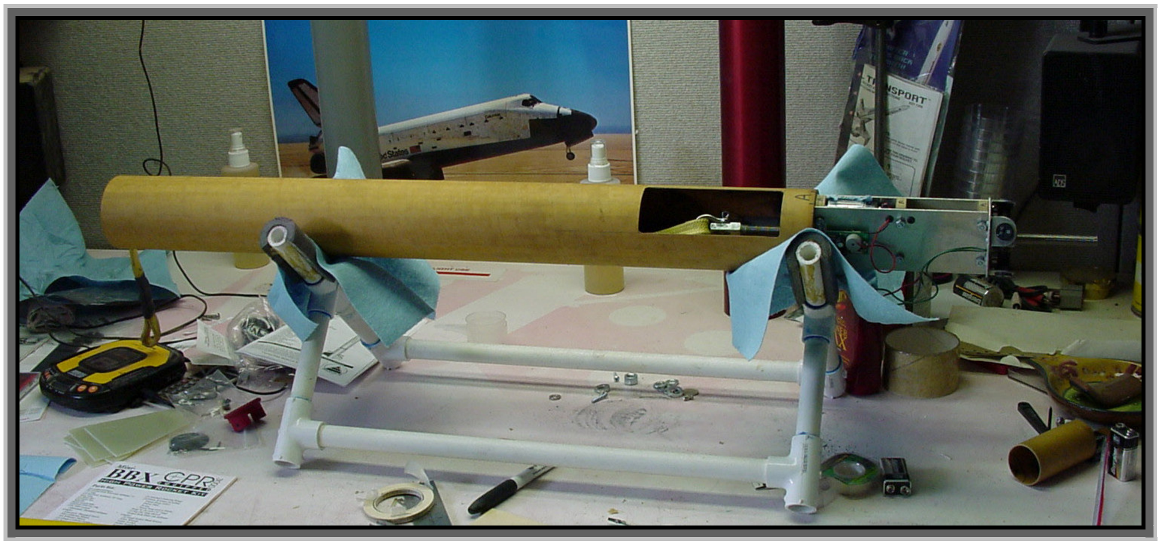


Plate #5 – Recovery Module

This photograph illustrates the internal component layout. The ejection tube is shown at left with the ejection bulkhead (not visible) installed at the aft end just below the ejection tube cutout. The stainless steel all-thread rod is shown threaded into the ejection bulkhead with the main recovery harness already mated to the shackle. The altimeters and switch plate are shown as well. A Perfect Flite MiniTimer is mounted on the altimeters platform (not used for L2 or L3 flights).

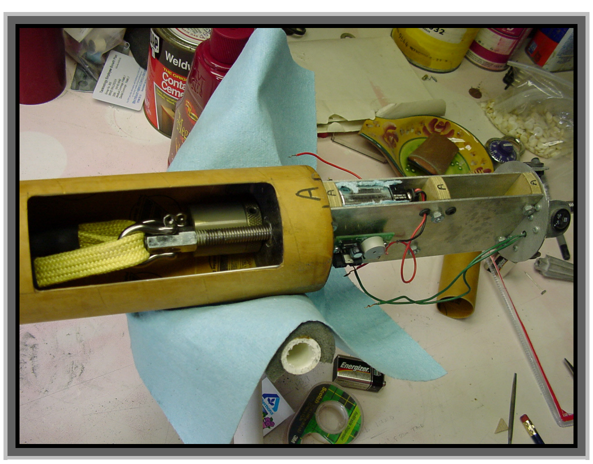


Plate #6 – Ejection Bulkhead

The ejection bulkhead can be seen in this picture along with the all-thread rod and ARRD. The ARRD harness is attached with an identical stainless steel shackle as used for the main harness. Just visible on the bottom edge of the ejection tube cutout is the aluminum conduit for the drogue charge leads. This conduit exits at the bottom of the ejection bulkhead and into the altimeter bay.

Section 3.4 – Altimeter Platform

The altimeter platform was constructed using sheet aluminum and 1/4" plywood ribs. A hole in the center of the structure allows the attachment rod to pass through. The entire structure is through bolted and can be quickly disassembled if necessary. The altimeter platform slips onto the 3/8" all thread rod and is followed by the switch plate. Both platforms are secured by a 3/8" bolt that can be seen nestled in the switches.

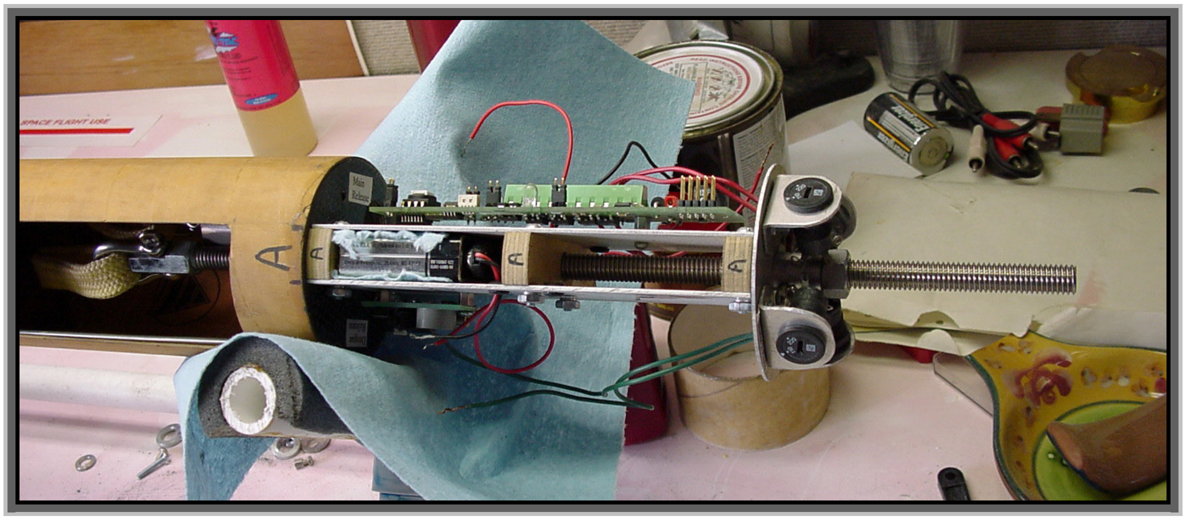


Plate #7 – Altimeters Platform

This picture illustrates the altimeters platform and the switch plate. The altimeters platform slides onto the 3/8" all-thread rod through holes in the platform ribbing. The ribbing is sized to create four battery compartments, two of which can be seen in this photograph. One battery is already installed.

Section 3.5 – Switch Plate

Like the altimeter platform, the switch plate is constructed of 1/16" aluminum sheet with a concentric 3/8" hole for passage of the all thread rod. Ninety degree aluminum angle mounts are attached to the switch plate with #4 bolts at 90 degree intervals on the switch plate. Holes in the aluminum angles were drilled for the Missile Works two pole, single throw heavy duty switches used. The aluminum angles allow the switches to be longitudinally mounted per manufacturer's recommendation. Each switch is capable of handling two separate, independent devices. Two of the four switches are used as deployment charge shunts and two are used as flight computer power application. In launch configuration, one drogue charge and one ARRD charge are wired to one switch and the redundant charges are wired to the other switch. Power for each flight computer is wired into the other two switches. After the wires were twisted onto the switch posts, each wire was soldered onto its post and then potted in five minute epoxy.

Plate #8 – Switch Plate

This picture illustrates the switch plate and the mounting of four Missile Works two pole, single throw heavy duty switches. Aluminum angles are attached to the switch plate with #4 bolts.

Section 3.6 – Airframe

Performance Rocketry carbon fiber tubing was used in the construction of the airframe. As shipped, each airframe section was three feet long. A 7" long carbon fiber coupler tube was used to join the airframe halves together. Prior to joining the airframes together, the fit of the coupler tube inside the airframe was too loose. A single wrap of 1.8 Oz fiberglass laminated to the exterior surface of the coupler using Shadow Composites laminating epoxy provided a snug fit inside the airframe. Next, the coupler tube was marked 3.5 inches from one end to ensure it was inserted the correct distance. The coupler tube was also sanded once using 120 grit to take off the amine laminating sheen. Then, it was sanded once more with 60 grit to scuff the surface enough to provide a tight fit inside the airframe. The interior of the airframe was similarly sanded. Aeropoxy structural adhesive was mixed and spread thinly in the forward end of the bottom section of airframe tubing. The attachment bulkhead was then slid into the airframe and the coupler tube was used to insert it the correct depth of 3.5 inches. The coupler was then removed and another layer of structural adhesive was spread inside the airframe above the attachment bulkhead in addition to the exterior portion of the coupler tube to be bonded. The coupler was then inserted into the airframe until it rested on top of the attachment bulkhead. This assembly was then allowed to cure completely.

Next, the forward airframe section was bonded to the aft airframe section coupler tube using structural adhesive to ensure proper alignment. Steel square section rails were placed on the top of the work bench, spaced parallel to one another, and taped into place. Aeropoxy structural adhesive was spread thinly on the inside of the aft end of the forward airframe tubing and also to the exterior of the aft airframe coupler tube. The forward airframe tubing was slid into place on top of the coupler tube and excess adhesive removed from the exterior of the airframe. Due to the minimal clearances between the altimeter platform/switch plate and the interior of the airframe, great care was taken to remove all excess adhesive from the inside of the airframe. The combined airframe tubing was then set on the square section steel rails to ensure the combined airframe sections were perfectly straight through the curing process. A small lightbulb was inserted into the airframe until it rested in the coupler tube. This served to increase the temperature significantly at the bonding surfaces thus decreasing cure time and increasing cure strength.

After the combined airframe cured, a Giant Leap Rocketry slim line motor retainer was bonded to the aft end of the airframe using JB Weld per manufacturer's recommendations. The exterior surfaces of the carbon airframe were prepared with 120 grit and 60 grit sandpaper. JB Weld was applied to both the slimline retainer and the aft end of the airframe. The retainer was then slid into place and excess adhesive removed.

Plate #9 – Coupler Tube

This picture illustrates the carbon fiber coupler tube and attachment bulkhead prior to insertion and bonding in the carbon fiber airframe sections.

Section 3.7 – Fins

Three fins provide aerodynamic stabilization for Carbon-Copy. Each fin was cut from 1/8 inch thick Alcoa T6061 aluminum. Only the leading edge of each fin was filed to a sharp edge. The carbon airframe was prepared for fin mounting by marking the airframe with fin alignment lines (wrapper printed out using wRASP) and then lightly sanding the carbon airframe fin attachment points. Prior to mounting, each fin root edge was given multiple notches to increase the effective bonding surface area. In addition, epoxy holes were drilled along the root edge to create epoxy channels. The epoxy channels allow epoxy from both sides of the fins to cure together and form one integrated structure. JB Weld was used to mount the fins onto the airframe for alignment purposes only. Once mixed, the JB Weld was sanded into the root edge of the fins and forced into each notch to ensure a good fin/airframe bond. A fin alignment jig was used to hold the fins tightly against the airframe at the proper orientation. A small lightbulb was inserted in the aft end of the airframe to heat the JB Weld, speed the cure time, and increase the bond strength. An electric foot heater was also used to ensure elevated temperatures over the entire bond area. After the JB Weld had cured, Shadow Composites temperature resistant epoxy was mixed with Kevlar® pulp for a thick consistency. This mixture was then applied to the fin roots and forced through the epoxy holes. A tongue depressor was used to shape the epoxy fillets. The fillets were allowed to cure for 7 seven days prior to sanding to achieve a smooth fillet shape. Great care was taken to sand only enough to achieve a rough fillet shape. Two layers of 10.8 Oz carbon fiber were then laminated over the fillets, one four inches wide and one two inches wide. Aeropoxy laminating adhesive was used for these laminations. Prior to laying down the first laminate, the laminating adhesive was sanded into the fin aluminum to ensure proper bonding between the carbon fiber and aluminum. The laminations were allowed to cure for 48 hours before the airframe was prepared for finishing.

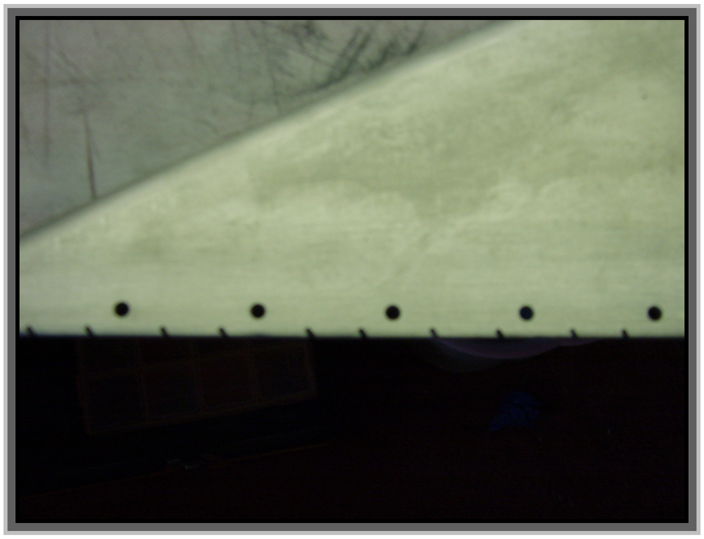


Plate #10 – Fins 1

This picture illustrates the notches cut into the root edge of each fin. Note that the notches are angled slightly forward. Also visible are the epoxy holes. These holes provide channels for the epoxy to flow through such that the epoxy used for the fillets forms a complete, integrated structure on both sides of each fin.

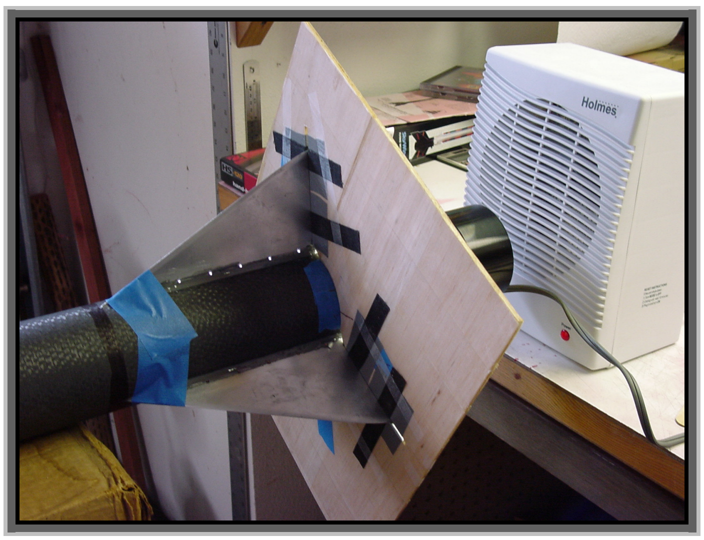


Plate #11 – Fins 2

JB Weld was used to attach the fins to the airframe. Although not structural, the JB Weld's slow curing time and high heat resistance make it an ideal adhesive for fin mounting. The power cord in this picture leads to a small light bulb used to heat the airframe and thus the epoxy. The small foot heater also helps to elevate the epoxy temperature, speed cure time, and increase bond strength.

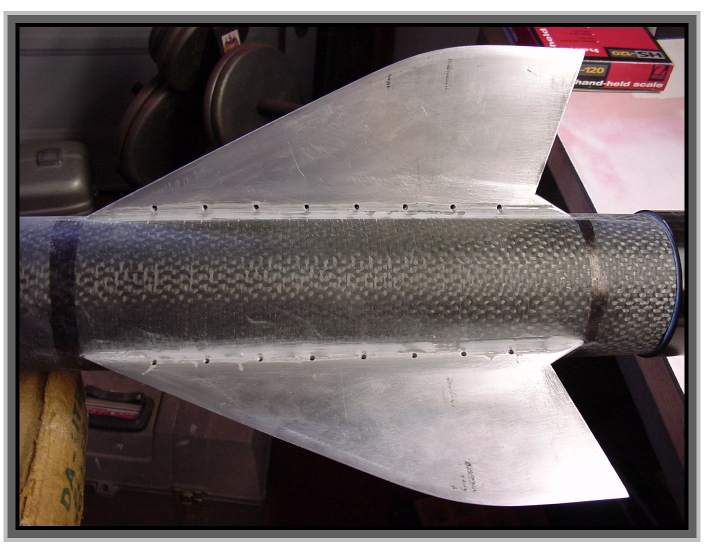


Plate #12 – Fins 3

Initial fin mounting complete. The black bands on the airframe are reference marks to ensure the fins are properly positioned fore and aft. Note that the epoxy holes are not filled but all fin root notches are filled. Visible in this photograph is the Giant Leap Rocketry Slimline motor retainer. The motor retainer was bonded into place with JB Weld.

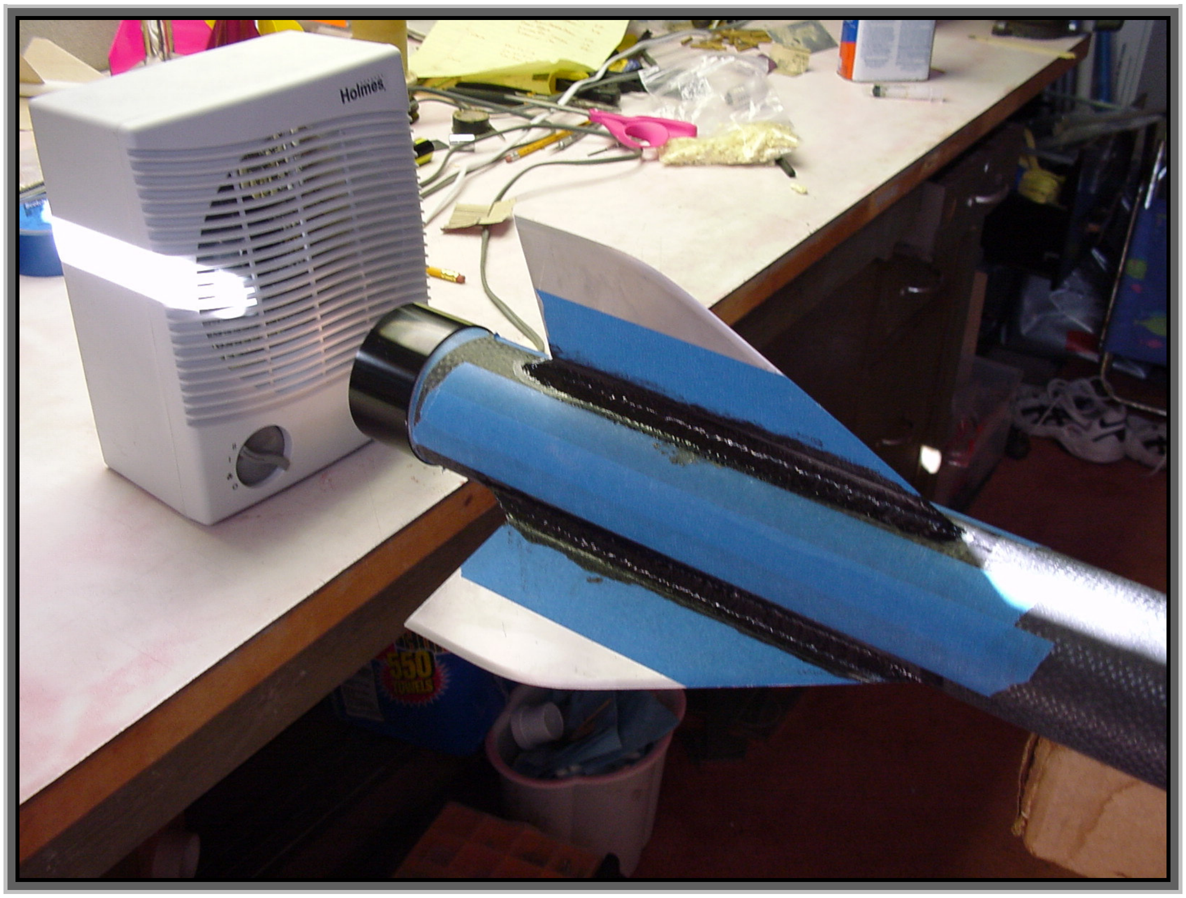


Plate #13 – Fins 4

This picture illustrates application of the Shadow Composites high temperature epoxy to the fillets of each fin. The masking tape eases cleanup after the epoxy has cured. Note the lumpy consistency of the epoxy due to the addition of Kevlar® pulp.

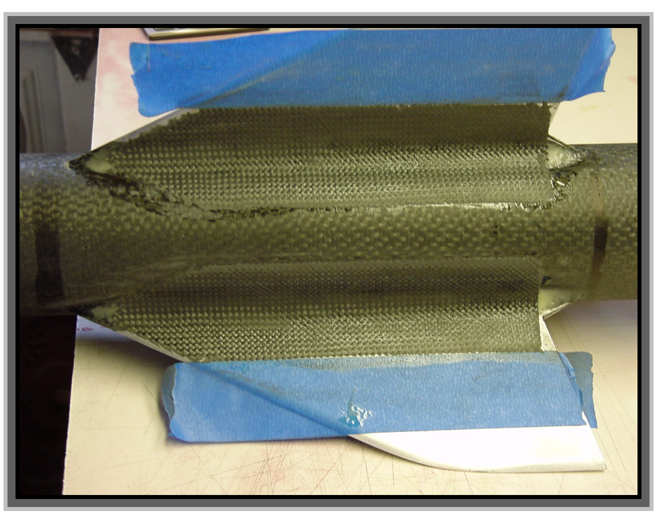


Plate #14 – Fins 5

The first application of the carbon fiber laminate to the fin root is shown in this photograph. Prior to application, the fin root fillet was sanded to achieve a rough fillet shape. To ensure superior bond strength between the carbon fiber and aluminum, the laminating epoxy was sanded into the aluminum to remove all oxidation on the aluminum.

Section 3.8– Nosecone

The nosecone is a Performance Rocketry carbon fiber 6:1 ogive. As delivered from Performance Rocketry, the nosecone required extensive sanding to achieve a proper aerodynamic shape. Much of the gelcoat had to be sanded down to the carbon fiber structure before a good shape was achieved. A circular bridle made of 5/8 inch tubular Kevlar was placed inside the nosecone such that one loop of the bridle lay in the tip of the nosecone and one loop extended past the shoulder of the nosecone. This loop was then bonded into place using Shadow Composites laminating epoxy. Once this cured, the interior was then filled with PML expanding foam with the tubular Kevlar loop in place. A small balsa box was pushed into the wet foam to serve as a bay for the Rocket Hunter transmitter. Once the foam cured, a carbon fiber/balsa bulkhead was bonded to the interior at the nosecone/shoulder transition while keeping the loops of tubular Kevlar pressed against the side of the nosecone. Finally, an access hatch was made with sheet aluminum for access to the interior of the balsa transmitter bay.

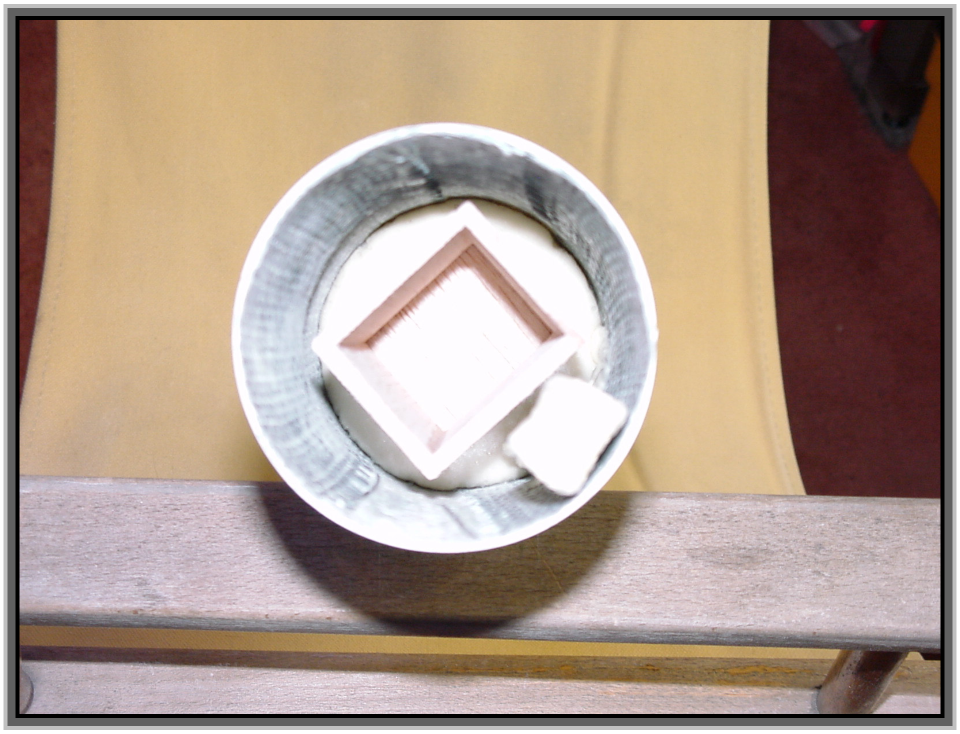


Plate #15 – Nosecone

The interior of the nosecone can be seen in this view including the carbon fiber nosecone structure. The tubular Kevlar® nosecone bridle can be seen in the lower right hand corner. The bridle is anchored to the nosecone with a large application of laminating epoxy in the nosecone tip and smaller applications of laminating epoxy on the nosecone side. The balsa box will serve as the Rocket Hunter transmitter bay. It has been pushed into the wet foam while the foam was still expanding to secure it into place. One more application of foam will be made such that the foam is roughly even with the top of the box.

Section 3.9 – Recovery Harnesses

All three recovery harnesses (main parachute, drogue parachute, and ARRD retention) were constructed using 5/8" tubular Kevlar®. The main recovery harness used to attachment the Rocketman R4C to the stainless steel rod is seventeen feet long. The drogue recovery harness used to attach the Rocketman R24D to the R4C crown is six feet long. The ARRD retention harness is two and half feet long. The loops at the end of each harness were made by ***carefully*** pushing aside strands of Kevlar® such that a zinc-plated steel bolt could be inserted through both pieces of tubular Kevlar ***without*** damage to individual strands. A liberal amount of Aeropoxy was used to bond the loops together. Aluminum backing plates were used to squeeze out excess epoxy as the bolts were tightened down.

Plate #16 – Recovery Harnesses

The completed recovery harnesses are shown in this view, main recovery harness in foreground and drogue recovery harness in background. The slight discoloration around the aluminum backing plates is due to the Aeropoxy laminating epoxy.

Section 3.10 – Finishing

Two epoxy compatible compounds were used to finish Carbon-Copy, Shadow Composites SuperFil and UV Smooth Prime. SuperFil was used primarily as a filler for areas where multiple layers of carbon fiber left ridges and gaps and other areas where the carbon fiber weave was insufficiently filled by resin at the time of layup. In particular, the area of the fin fillets, the airframe joining area, forward end of the airframe, and the nosecone all required multiple applications of SuperFil. After there areas were filled and sanded smooth, UV Smooth Prime was applied to fill the smaller pinholes in the airframe material. After one application of Smooth Prime cured, the airframe and fin fillets were sanded smooth and the process repeated. Four applications of Smooth Prime and a final sanding with 1200 grit sandpaper produced a perfect surface for paint application. A simple paint scheme was selected. Testor's metallic purple paint in small rattle cans was used for the aft one third of the airframe and fins while Rustoleum metallic silver paint was used for the forward two thirds. Custom made vinyl graphics were then applied.

Plate #17 – Finishing

The completed rocket is shown in this photograph. Author's son, Garrett, is doing the honors. Just visible in this photograph is one of four access holes for the switches. The hole is denoted by the small red vinyl application. The access holes also double as pressure equalization ports.

SECTION 4.0 – RECOVERY SYSTEM DETAILS

Section 4.1 – General Description

As stated in Section 1.5, Carbon-Copy uses a dual deployment system for recovery. Dual deployment is achieved through a single forward airframe opening by use of a Blacksky ARRD. A GWiz MC is the primary flight computer and this is backed up by a GWiz LCD 800. Separate drogue charges and main ARRD charges provide redundancy. The drogue parachute is a Rocketman ProXP R24D constructed of 1.9 Oz. ripstop nylon and the main parachute is a Rocketman ProXP R4C also constructed of 1.9 Oz. ripstop nylon. The main harness, drogue harness, and ARRD retention harness are all constructed of Pratt Hobbies 5/8" tubular Kevlar. See Section 3.9 for details of harness construction.

Plate #18 – Recovery System Detail

The completed recovery system as installed in Carbon-Copy is shown in this view. A component listing is shown at the right. The main recovery harness is attached to the all-thread rod in the altimeter/ejection module not visible in this view.

Section 4.2 – Deployment Sequence

1. Launch is initiated
2. Altimeters sense acceleration, start integrating acceleration and barometric data
3. Altimeters sense apogee and fire drogue charges
4. Drogue charges pressurize parachute compartment in ejection tube
5. Components forward of drogue charges are ejected out of airframe:
    a. Nosecone
    b. Drogue parachute
    c. Drogue harness
6. ARRD retains main parachute in ejection tube
7. Carbon-Copy descends rapidly under drogue parachute
8. At 800 feet AGL, altimeters fire main charge in ARRD
9. ARRD releases retention harness
10. Drogue parachute pulls main parachute out of ejection tube
11. Carbon-Copy completes descent under main parachute

Section 4.3 – Parachute Compartment and Closures

The parachute compartment of Carbon-Copy is 30 inches long, 2.75 inches in diameter, and is defined by the space between the ejection bulkhead and the internal nosecone bulkhead.

Section 4.4 – Parachutes

A Rocketman ProXP R24D is used as a drogue parachute. At a weight of 10 pounds (expected weight of rocket and motor casing at motor burnout), the R24D provides a descent rate of 68 feet per second. The main parachute is a Rocketman ProXP R4C. Once deployed, this parachute will provide a descent rate of 32 feet per second. The R4C was selected due to the necessity of the recovery system design. The deployment of the R4C is a ***passive*** event and is not caused by forceful ejection with deployment charge gases. Rather, the R4C must ***slide*** out of the ejection tube easily (pulled out by the R24D) for proper deployment. An oversized parachute that could not slide in and out of the ejection tube would not ensure successful deployment. As such, an undersized parachute was selected.

At this point, it must be noted that although a descent rate of 32 FPS is considered high by HPR standards, it in no way poses a risk of landing damage to Carbon-Copy. Because Carbon-Copy is a three inch, minimum diameter rocket, there is a tremendous amount of strength in the aft end of the airframe. When configured for its L3 flight, the aft end of Carbon-Copy includes a Slimline aluminum motor retainer, carbon fiber airframe material, and a Dr. Rocket aluminum motor casing. All of these components are layered right next to one another. In addition, the fins of Carbon-Copy are mounted well forward of the aft end of the airframe and will not impact the ground first. Both test flights, as described below, were very successful and landings were uneventful. No damage of any kind was evident.

Section 4.5 – Control Devices

A GWiz MC is used as the primary control device. The MC is backed up by a GWiz LCD 800. Both units utilize an accelerometer, a barometric pressure sensor, and proprietary software to determine rocket flight events including detection of apogee at a preset altitude. Four 9VDC batteries power the CPU's and pyrotechnic functions of both the MC and LCD, two batteries for each altimeter. The CPU batteries are wired into Missile Works switches for safe and arming control. Each altimeter is mounted onto the avionics platform using steel standoffs, split washers, and bolts on both the altimeter side and underneath the avionics platform (through bolted). This mounting method results in a very robust, solid mount.

Section 4.6 – Pyrotechnic Devices

Drogue charges are constructed using Aerocon small size ejection canisters, 4F black powder, and Daveyfire N28B low current e-matches. A small hole is drilled in the base of the ejection canister. The e-match is stripped of the green plastic protective cover over the pyrogen, and the leads are threaded through the hole in the canister. A small amount of five minute epoxy is placed just under the pyrogen head prior to pulling the e-match all the way down in the ejection canister. The epoxy seals the bottom end of the canister. Once the epoxy is dry, the canister is filled to capacity with 4F black powder. This equates to 2.0 grams. The top of the canister is covered and glued into place with plastic cement to seal the top of the canister. One wrap of electricians tape around the top of the canister is used to ensure a complete burn of all black powder at altitude.

Section 4.7 –Recovery System Attachment Hardware

A unique system was used to ensure robust recovery component attachment. The main harness is attached to the rocket using an all thread hexagonal rod bolt that has been through-drilled while on the all thread rod. A stainless steel marine grade shackle is mounted onto the bolt/rod assembly. The shackle is rated at 1,360 pounds. The shackle pin is inserted into the hole drilled through both the bolt and rod. In this way, the shackle pin prevents the bolt from unthreading off the all thread rod. The all thread rod, in turn, is bolted onto the ejection bulkhead, once on top of the ejection bulkhead (seen recessed in Plate #21) and again just below the switch plate. The ARRD harness uses the same stainless steel shackle mounted onto the top of the ARRD release pin. As stated previously, the ARRD is through bolted into the ejection bulkhead.

Plate #19 – Main Harness Attachment

The main harness attachment is detailed in this photograph. The hexagonal all thread rod bolt was through drilled while mounted on the rod such that the shackle pin threads through the bolt and rod. This shackle pin prevents the bolt from unthreading off the all thread rod.

Section 4.8 – Attachment of Parachutes, Drogue Harness, and Nosecone

As can be seen in Plate 20, the main parachute is attached to the end of the main harness with a simple loop. The loop at the end of the main parachute shrouds is inserted into the loop at the end of the main harness. The main parachute is then slipped through the shroud loop and pulled all the way through and cinched tight to the end of the main harness. Once the main harness is coiled in the base of the ejection tube prior to launch, the crown loop at the top of the main parachute (now attached to the top of the main harness) is joined to the top of the ARRD harness using a quick link. The drogue harness is attached to the top of the ARRD harness using the loop tying method described above. The drogue parachute is attached to the top of the drogue harness is the same manner. The nosecone is attached to the top of the drogue harness using another quick link.

Section 4.9 – Protection of Parachutes

Pratt Hobbies Kevlar® heat shields are used to protect both the main and drogue parachutes from the burning ejection charge gasses. Pratt heat shields are used to sandwich the drogue ejection charges and prevent the hot gases from burning either the main or drogue parachutes.

Section 4.10 – Parachute Compartment Venting

A small 1/8" hole is drilled through the airframe just below the nosecone shoulder to prevent air trapped inside the ejection tube from pushing the nosecone off during ascent of the rocket.

Section 4.11 – Recovery System Ground Testing

The recovery system was tested on three separate occasions to ensure the pyrotechnic charge pressurized the parachute compartment with enough force to quickly and reliably eject the drogue parachute and drogue harness. Using the 2.0 gram pyrotechnic charge described above, the recovery system was assembled such that the charge leads for both the drogue charge and ARRD charge were routed outside the airframe. Upon contact with a standard 9VDC battery, the drogue charge deployed the drogue chute, harness, and nosecone convincingly of all three occasions. The nosecone had enough momentum form the ejection charge to jerk the airframe considerably. The ARRD charge also worked perfectly and each time caused the ARRD to release the main parachute and main harness. The ease with which the main parachute and harness cannot be overstated as the drogue chute must pull these components out of the airframe.

Section 4.12 – Recovery System Flight Testing

As a final test of the recovery system, Carbon-Copy was launched on 1/10/04 using an Aerotech J275 and then again on 3/13/04 using an Aerotech J415. Both flights were nominal and the recovery system worked perfectly. Deployment of the drogue parachute occurred just after apogee on both flights. At the preset altitude of 800 feet, the altimeters fired the main charge in the ARRD and the rocket simply fell away from the drogue parachute to deploy the main parachute. Once inflated, the nosecone and drogue parachute remain suspended from the crown loop on the top of the main parachute canopy. No damage of any kind was visible even after close inspection. The parachutes were not burned and the rocket itself had no visible evidence of damage of any kind.

SECTION 5.0 – STABILITY EVALUATION

Section 5.1 – Stability Calculations

RocSim® 5.0 was used to both design Carbon-Copy and ensure that the design provided enough stability for use with a broad range of motors. The following pages (pages 22 to 45) illustrate the CP/CG relationship for J class motors and M class motors as calculated by RocSim®.

Section 5.2 – Static Margin of Stability

The table below provides the static margin of stability as calculated by RocSim® for some sample motors:

Motor Type	Calibers of Stability
J275	3.45
J415	2.97
K560	1.32
L850	0.93
L1120	0.81
M1315	1.03

Once the CP was determined by RocSim®, an adhesive marker was applied on Carbon-Copy to identify the CP. For the flights using the J275 and the J415, the static margin of stability was slightly greater than that predicted by RocSim®. The author feels confidant that the slightly low stability number for the M1315 is conservative. As part of the pre-flight checklist and launch checklist, a manual check of the static margin of stability is required to ensure the CG is ahead of the CP. In addition, as with any rocket, the margin of stability with increase rapidly in the first few seconds of flight

Section 5.3 – Launch Rails

Giant Leap Rocketry conformal rail guides were epoxied onto the airframe. For the flights on the J275 and J415, a six foot launch rail was utilized. No instability was noted once the rocket cleared the rail. For the M1315 flight, a 12 foot rail will be utilized to ensure adequate stability off the pad.

SECTION 6.0 – EXPECTED PERFORMANCE PROFILE

The RocSim® estimated performance profiles illustrated on pages 22 to 45 compare favorably with the actual performance of Carbon-Copy using both the J275 and J415. Actual performance was approximately 10% less than predicted for both flights. The details of both flights as recorded by the GWiz MC are shown in the following pages (pages 47 to 54).

SECTION 7.0 – PRE-LAUNCH CHECKLIST

Follow the directions below in the sequence printed. Failure to follow this sequence may result in damage to the altimeters, recovery system failure, or rocket flight failure.

☐ **1) ARRD PREPARATION**

- ◯ a) Prepare two Daveyfire N28B e-matches by removing green plastic cover over pyrogen and cutting wire leads to 8” in length.
- ◯ b) Insert both N28Bs into ARRD charge holder.
- ◯ c) Insert N28B leads through ARRD aluminum base – ensure leads are straight with no kinks.
- ◯ d) Continue to pull leads through ARRD base until plastic charge holder rests in ARRD aluminum base.
- ◯ e) Carefully bend N28B pyrogen head to fit in plastic charge holder.
- ◯ f) Insert small piece of rubber insulation material between pyrogen heads to prevent possibility of shorting.
- ◯ g) Pour 4F black powder into cavity in plastic ARRD base..
- ◯ h) Cover plastic ARRD base with sticker to prevent loss of black powder.
- ◯ i) Thread ARRD aluminum base into ARRD main body.

☐ **2) ARRD MOUNTING**

- ◯ a) With 3/8” all thread rod installed loosely in ejection bulkhead, slide ARRD assembly into position in ejection tube.
- ◯ b) Run N28B e-match leads from ARRD through ejection bulkhead into altimeter bay.
- ◯ c) Slid 3/16” ARRD threaded mounting rod through ejection bulkhead while sliding 3/8” all thread rod in unison with ARRD until both bottom out in ejection bulkhead.
- ◯ d) Secure ARRD to ejection bulkhead by threading split washer and nut onto ARRD threaded mounting rod from altimeters bay side.

☐ **3) ALTIMETER BAY ASSEMBLY**

- ◯ a) Slide altimeter platform onto 3/8” all thread rod up against 3/8” nut at base of ejection bulkhead.
- ◯ b) Align altimeter platform with markings on ejection tube.
- ◯ c) Slide switch plate onto 3/8” all thread rod until it butts against altimeters platform. Ensure alignment of switch plate by matching markings on altimeter platform ribs.
- ◯ d) Slide aluminum spacer tube onto 3/8” all thread rod and into switch plate area.
- ◯ e) Secure switch plate with a 3/8 nut.

☐ **4) ALTIMETER PREPARATION**

- ◯ a) Check voltage and amperage of NEW 9VDC batteries to ensure correct operation of altimeters.
- ◯ b) Slide one ARRD e-match lead through platform to MC side of altimeter platform thus leaving one lead on the LCD 800 side of the platform.

- c) Mount MC and LCD 800 using supplied standoffs and hardware and secure to altimeter platform.
- d) Slide one drogue e-match lead to LCD side of altimeter platform thus leaving one drogue e-match lead on the MC side.
- e) Insert 9V connector wires through platform holes at all four battery positions.
- f) Ensure all four switch positions are set to "OFF."
- g) Wire power circuits to appropriate switches and terminal blocks on MC and LCD 800.
- h) Wire drogue and main charges to appropriate switches and terminal blocks on MC and LCD 800
- i) Connect 9VDC batteries to connectors.
- j) ***CRITICAL STEP*** - Check circuit completion by turning on switches to MC and LCD:
  - i) ***For LCD, ensure appropriate LEDs are flashing continuity***
  - ii) ***For MC, ensure appropriate LEDs are flashing continuity and continuity tones are correct***
  - iii) ***After continuity checks are complete, set all switches to "off"***
- k) Wrap connectors and batteries with two wraps of cellophane tape.
- l) Insert batteries and connectors into battery bays in altimeter platform.
- m) Insert balsa blocks in open spaces between top of battery connectors and altimeter platform ribs.
- n) Affix one strip of clear packing tape over both sides of altimeter platform to ensure batteries cannot slip out of the battery bays.
- o) Affix one strip of clear packing tape over the terminal blocks of both the MC and LCD 800 to ensure the wiring does not interfere with the installation and removal of the altimeter module.

5) RECOVERY SYSTEM INSTALLATION

- a) Thread main recovery harness into ejection tube.
- b) Attach main recovery harness to stainless steel shackle on top of the 3/8" threaded rod.
- c) Thread ARRD harness into ejection tube and let hang to one side.
- d) Attach ARRD harness to stainless steel shackle on top of ARRD.
- e) Press successive loops of main recovery harness into space between 3/8" threaded rod and ejection tube being careful not to jam harness in too tightly.
- f) Continue looping in recovery harness until most material is loosely placed in Ejection Tube and not jammed against ARRD Harness.
- g) Attach main parachute to main recovery harness using a simple loop.
- h) "Z" fold main parachute such that parachute crown loop is pointed forward and wrap shrouds tightly around parachute such that it slides easily into ejection tube.
- i) Slide main parachute into Ejection Tube and ensure top of ARRD Harness is still at top of ejection tube.
- j) Attach crown loop at top of main parachute to top of ARRD Harness with stainless steel quick-link and tighten.
- k) Attach drogue harness to top of main harness with a simple loop.

- l) Slide one Kevlar® heat shield onto the drogue harness and gently pack into ejection tube until it is snug on top of the main parachute.
- m) Bend both drogue ejection charges down into the ejection tube until they are resting on the Kevlar® heat shield just installed.
- n) Slide the other Kevlar® heat shield on top of the drogue ejection charges.
- o) Coil the drogue harness on top of the heat shield in the ejection tube until one end extends slightly from the forward end of the ejection tube.
- p) Attach the drogue parachute to the forward end of the drogue harness using a simple loop.
- q) Attach the nosecone harness to the forward end of the drogue harness using a quick link.
- r) Tri-fold the drogue parachute and tightly wrap the suspension lines around the parachute.
- s) Insert the drogue parachute into the ejection tube.

6) ATTACHMENT OF RECOVERY MODULE

- a) Slide fender washer onto end of 3/8" all thread rod
- b) Slide recovery module into rocket airframe until 3/8" all thread rod slips through hole in attachment bulkhead
- c) Align recovery module with markings inside airframe
- d) Seat recovery module by tapping bottom of airframe on ground
- e) Secure recovery module to attachment bulkhead by threading 3/8" bolt though aft airframe using specialized tool
- f) Ensure proper alignment of recovery module during tightening of bolt

7) ROCKET HUNTER TRANSMITTER INSTALLATION

- a) Insert fresh battery into Rocket Hunter transmitter
- b) Ensure transmitter is sending and signal strength is good
- c) Insert Rocket Hunter transmitter into nosecone bay
- d) Pack protective foam around transmitter
- e) Thread transmitter antennae through hole in nosecone bay cover
- f) Attach nosecone bay cover to nosecone bay bulkhead
- g) Slide nosecone into position

ROCKET IS NOW READY TO LAUNCH!
PROCEED TO LAUNCH CHECKLIST!

SECTION 8.0 – LAUNCH CHECKLIST

☐ ***1. Build motor per manufacturer's directions***
☐ ***2. Insert completed motor into aft airframe and lock in place using Slimline retainer ring***
☐ ***3. Perform final stability check using Cp marking on airframe***
☐ ***4. Ensure all charges are switched off and all altimeters are switched off***
☐ ***5. Check in with RSO for pad assignment***
☐ ***6. Mount rocket on launch pad rail ensuring rocket slides freely***
☐ ***7. Install igniter***
☐ ***8. Switch on all charges and altimeters***
☐ ***9. Ensure MC continuity tone is correct***
☐ ***10. Verify signal from Rocket Hunter transmitter is good***
☐ ***11. Move to safe flight line location***
☐ ***12. Ensure tracking receiver is on and working***
☐ ***13. Ensure person assigned to time to apogee is ready***
☐ ***14. Ensure video and cameras are ready***
☐ ***15. Ensure trackers are ready***
☐ ***16. Countdown and launch***

SECTION 9.0 – FLIGHT TESTING

As stated previously, Carbon-Copy was flight tested twice, once on a J275 for NAR Level 2 certification and once on a J415 to ensure system reliability. Both flights were nominal. Carbon-Copy exhibited perfect stability with no discernable wobble, coning, or spin. All systems performed flawlessly. Flight performance was approximately 10% less than predicted.

SECTION 10.0 – VENDOR LISTING

Vendor Name	Phone Number	Website Address
Rocketman Enterprises	1-800-732-4883	http://www.the-rocketman.com/
Performance Rocketry	1-814-536-8491	http://www.performancerocketry.com/index.html
GWiz Partners Limited		http://www.gwiz-partners.com/
Shadow Aerospace	1-530-544-7423	http://www.shadowaero.com/
Giant Leap Rocketry	1-225-769-6040	http://www.giantleaprocketry.com/hpdefault.asp
Rocket Hunter	1-866-462-9258	http://www.rockethunter.com/
Pratt Hobbies	1-703-689-3541	http://www.pratthobbies.com/
Blacksky Rocketry	1-760-730-3701	http://www.blacksky.com/
Doctor Rocket	1-775-751-9005	http://www.drrocket.com/
Aerotech Aerospace	1-435-865-7100	http://www.aerotechrocketry.com/

SECTION 11.0 – PLATE LISTING

Plate Number	Description
1	Attachment Bulkhead, aft side
2	Attachment Bulkhead, forward side
3	Ejection Bulkhead, forward side
4	Ejection Bulkhead, aft side
5	Recovery Module
6	Ejection Bulkhead
7	Altimeter Platform
8	Switch Plate
9	Coupler Tube
10	Fins 1, root edge detail
11	Fins 2, initial attachment
12	Fins 3, initial attachment
13	Fins 4, epoxy fillets
14	Fins 5, carbon fiber encapsulation
15	Nosecone
16	Recovery Harnesses
17	Finishing
18	Recovery System Detail
19	Main Harness Attachment

SECTION 12.0 – L3 FLIGHT SIGN OFF SHEET

Accepted By (print name): ______________________________

Accepted By (signature): ______________________________

Title: ______________________________

Date: ______________________________

Accepted By (print name): ______________________________

Accepted By (signature): ______________________________

Title: ______________________________

Date: ______________________________

Accepted By (print name): ______________________________

Accepted By (signature): ______________________________

Title: ______________________________

Date: ______________________________