NAR Level 3 Certification Package

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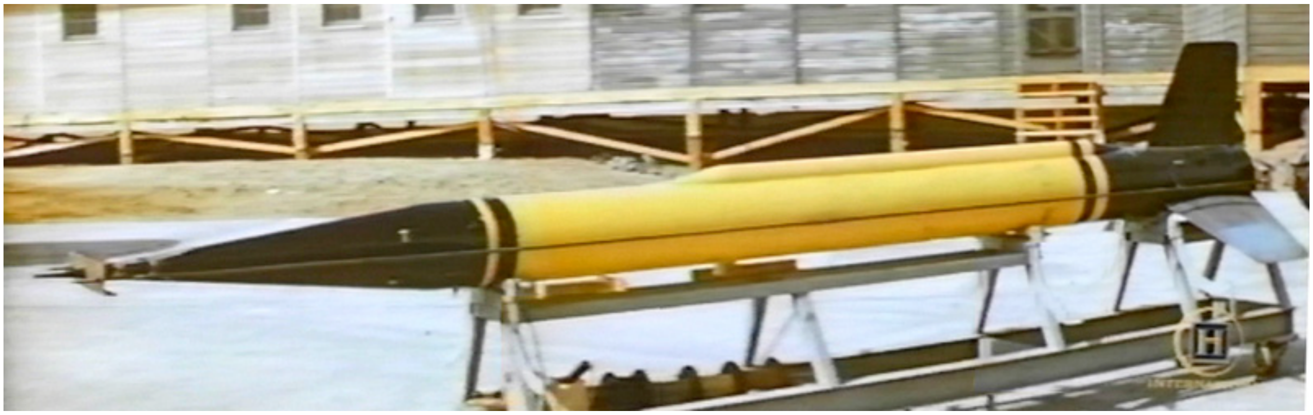
Project: WAC Corporal Round 5 Sustainer (97% scale model)



This certification package has been revised, with changes based on the outcome of the first certification flight attempt on 11 June 2005. Significant changes in design or procedure from the original plan are indicated in this document by red text.

I. Introduction

On September 11, 1966 I launched my first model rocket. It was the Estes starter kit – a scale WAC Corporal based on the BT-20 body tube. It flew on an Estes 1/2A.8-2 engine, and flew a second flight the same day on an A.8-3 before being retired from flight duty.

When considering a suitable Level 3 project, the WAC was a natural sentimental choice, and since the original WAC still survives in my collection, re-flying it as a payload in the Level 3 bird was suggested. In considering the scale for the project, I was influenced by my son who is particularly fond of the visual impact made by very large scale HPR projects. After some discussion we settled on a large "low and slow" design as close as possible to a full scale reproduction of the original.

The project is designed around the PML 11.4" diameter airframe and stands 16 feet high. The design incorporates a 98 mm motor mount, for the single-motor certification flight. Also included are three auxiliary 54 mm motor mounts for cluster/airstart flights later, or possibly also for stage coupling to a scale Tiny Tim booster if such a project is undertaken at a later date.

The certification flight will be carried out using a Hypertek M1001 hybrid motor. Designing around the single hybrid motor configuration, an important design constraint on the project has been to keep the weight as low as possible, so as to avoid takeoff speeds that are too low. The weight has been managed where possible with the use of lightweight construction materials and techniques. The dry weight for the rocket without motor is 68 pounds (31 kg) and the fuelled launch weight is 90 pounds (41 kg), which is within the original design target range for acceptable liftoff speed.

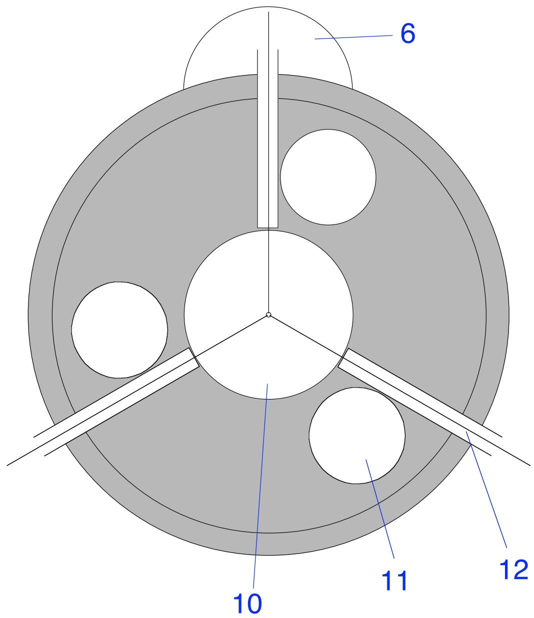
The expected peak altitude of the certification flight is 3560 feet (1085 meters), assuming vertical ascent and a drag coefficient of 0.55. (Actual reported altitudes from two altimeters on the first flight were 3796 feet and 4004 feet.) Recovery will be accomplished in two pieces, with the nose/payload section returning on a single parachute, and the tail and midbody sections returned via drogue/main dual parachute deployment. Most aspects of the design are relatively straightforward HPR practice, but there are a few novel features. Major weight savings have been realized through the use of lightweight honeycomb composite core material for the fins. The recovery bay of the rocket incorporates a 3” diameter reinforced ejection cannon, which effects separation of the rocket at apogee using a much smaller black powder charge than would be ordinarily needed to pressurize a full 12 inch diameter airframe. This design also greatly reduces the need for flame protection of the recovery system, since the main ejection charge is contained by the cannon. The remaining recovery volume is partitioned into chambers housing the various parachutes and recovery components.

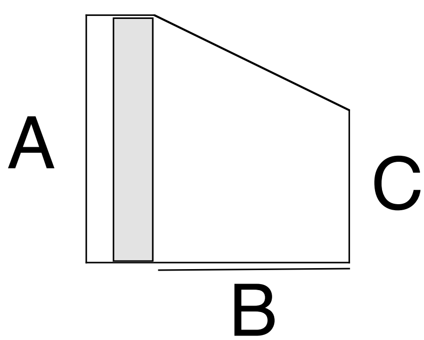
Another unique design feature makes use of the external conduit which is a scale feature of the original WAC Corporal. In this project, the conduit is constructed of 4” phenolic tubing, and serves as the volume housing the three electronics bays that control the flight recovery events. The rocket design does not entail any unusual risks or hazards, but the lightweight design philosophy requires some care in recovery. To avoid landing damage, all airframe segments are laminated with Kevlar fabric. As an additional measure against zipper or “ground slap” damage, the upper end of the midbody airframe has an extra lamination band of carbon/Kevlar woven cloth. (This feature has been eliminated in the redesign with the relocation of the coupler from the nose to the midbody section.)

II. Drawing and Dimensions

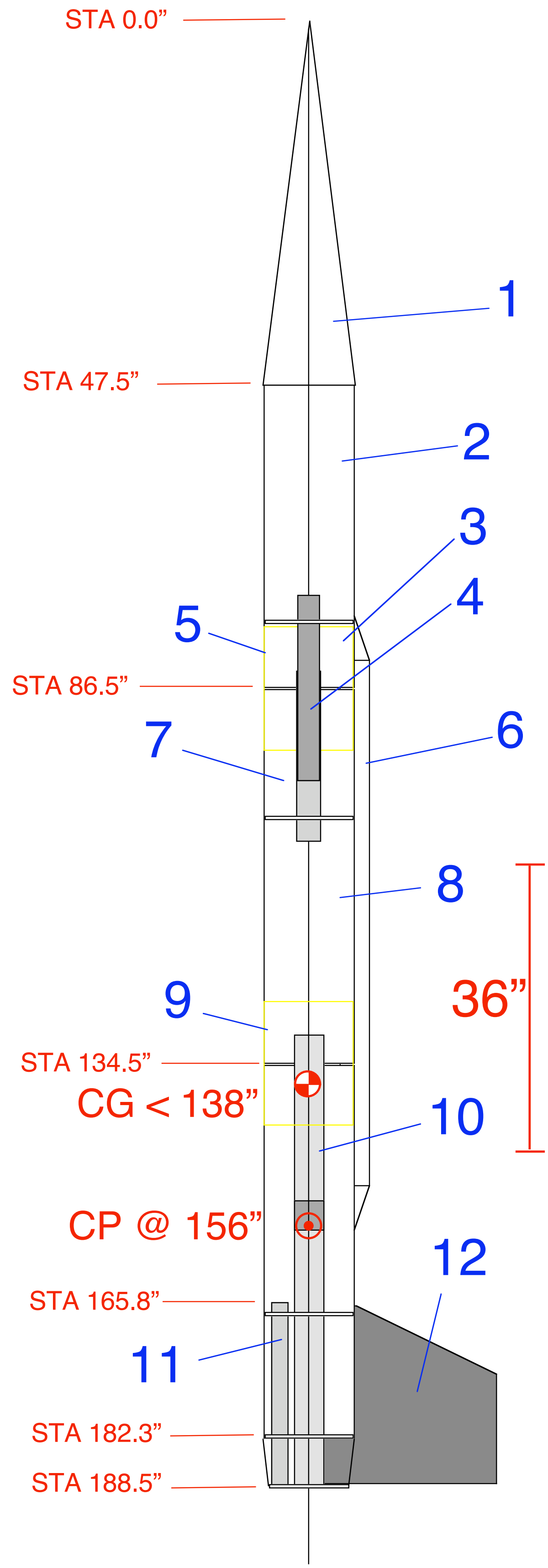
The basic layout of the rocket follows a fairly typical configuration for a single stage high power rocket with dual parachute deployment. The main airframe tube comprises the largest single item in the weight budget. Consisting of 11.4” phenolic tubing laminated with a single layer of 5 oz. Kevlar, it weighs approximately 340 oz. The nose cone is a fiberglass part fabricated by Performance Rocketry, and weighs in at 91 oz. To save weight, the three scale fins are fabricated from 1/2” thick Giant Leap honeycomb composite board, and built up to scale thickness with foam and covered with glass. The weight of the three-fin set is approximately 55 oz. Further details of the layout and construction are provided by the accompanying drawings. On the layout diagrams, the following specific items are called out:

1. Fiberglass nose cone
2. Payload airframe; 11.4” phenolic w/5 oz. Kevlar
3. Storage compartment for drogue and shock cords
4. 3” phenolic tube/coupler ejection cannon
5. 11.4” phenolic coupler
6. 4” phenolic external conduit for scale appearance and housing for electronics bays
7. Storage compartment for main parachute and shroud lines
8. Main airframe; 11.4” phenolic w/5 oz. Kevlar
9. 11.4” phenolic coupler
10. 4” motor mount tube
11. 54 mm motor mount tube (3)
12. Honeycomb composite fins





A = 22.7”
B = 17.5”
C = 14.0”
tab = 3.82”



The principal structural centering rings are made of 1/2" birch plywood and are located in the fin can region and in the recovery compartment/separation region. In addition to these main rings, lightweight ribs and gussets are provided for internal support of the motor tube and ejection piston against lateral forces. Sewn loop ¾" tubular nylon strap are used for the recovery harnesses. The design calls for the main and payload airframes to be returned separately under their own parachutes. Attached to the U-bolt hard point on the booster bulkhead are the drogue and main harnesses. Triggering of a pyro release mechanism will cause the drogue chute to pull out the main from its compartment in the upper part of the booster. Conventional stainless steel U-bolts and hardware are used for attachment to the bulkheads.

As shown in the diagram, the rocket's Barrowman center of pressure (CP) is located 156 inches from the nose. Accordingly, for a 1.5 caliber stability margin, the maximum permissible center of gravity (CG) position is 138 inches from the nose; this coincides approximately with the joint and coupler connecting the rear and midbody airframe segments.

III. Construction Package

Airframe materials:

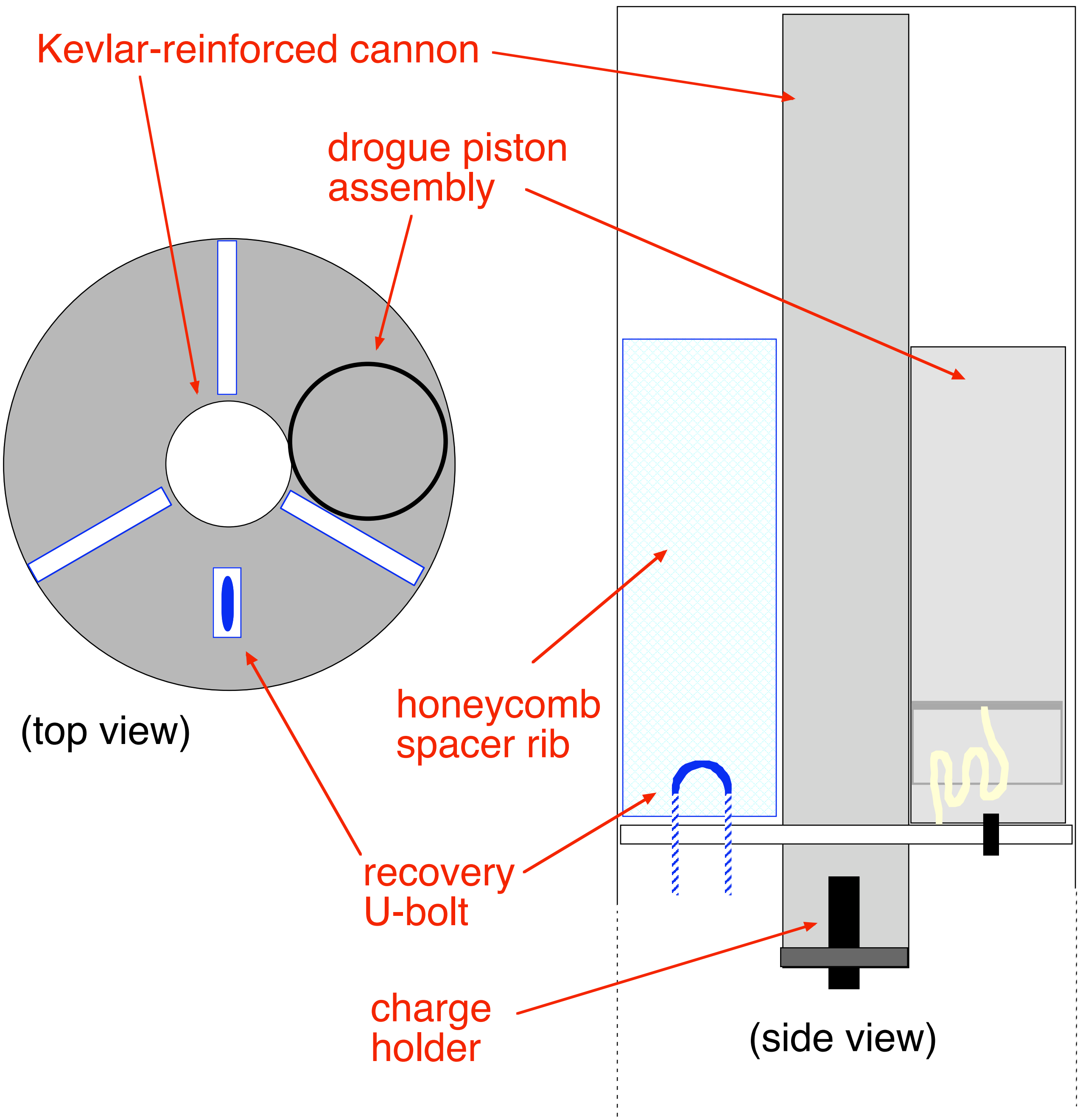
1) Body tubes – PML 11.4" phenolic laminated with 5 oz. Kevlar fabric
2) Fins – ½" honeycomb composite board from Giant Leap Rocketry
3) Centering rings – ½" Baltic birch plywood from PML
4) Custom machined Delrin launch rail guides (3)
5) Reinforcements – Carbon/Kevlar wrap and chopped fiberglass/epoxy fillet paste
6) West Systems epoxy – used for laminate layups and structural assembly
7) Nose cone – premanufactured fiberglass nose cone by Performance Rocketry

Construction techniques:

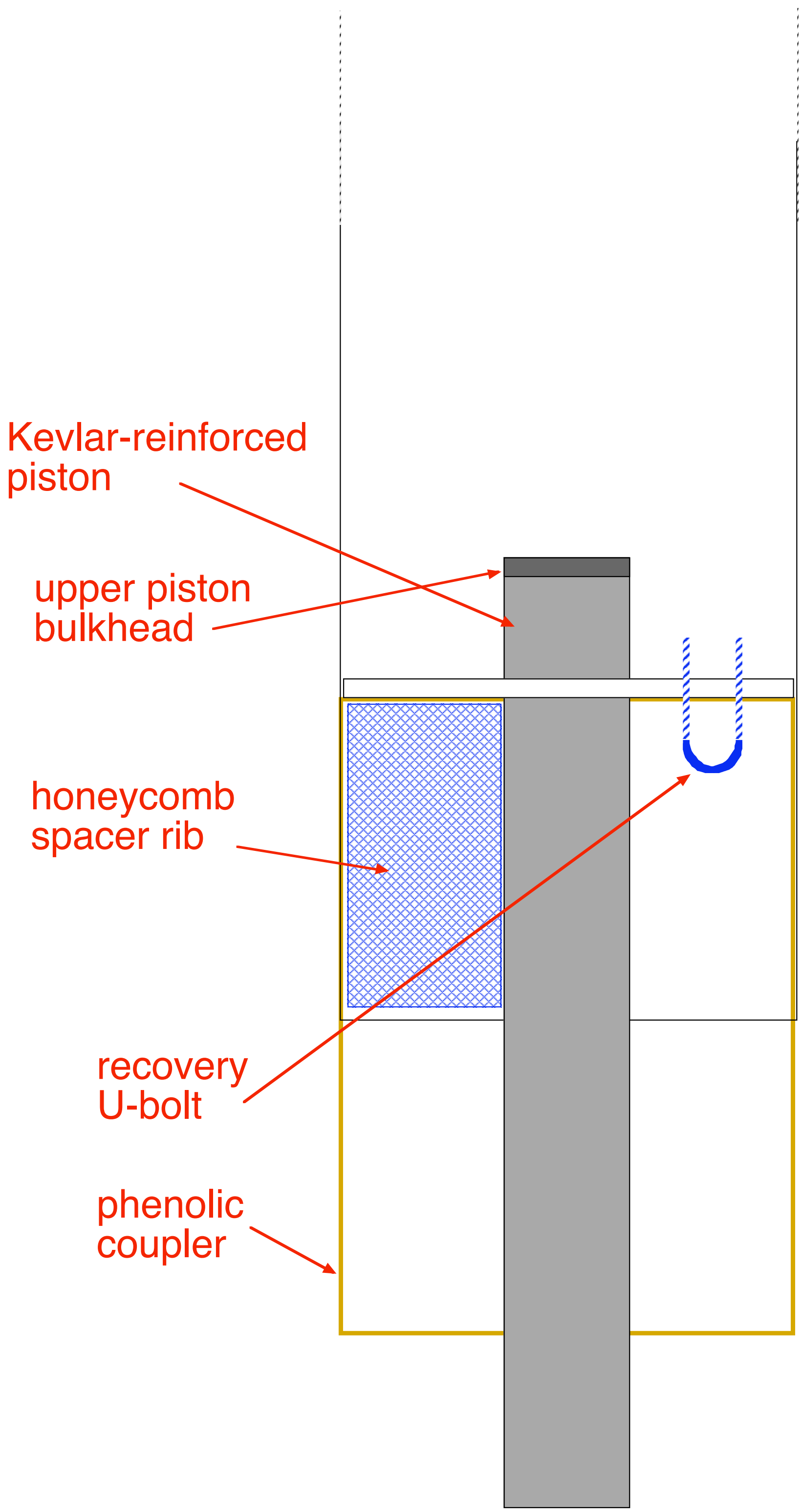
1) Fin mounting – fin tabs extend through slotted airframe and epoxied to central motor tube, auxiliary motor tubes, and fin can centering rings
2) Reinforcement – epoxy/glass fillets at all fin/tube and fin/bulkhead joints; internal ribs of honeycomb board also used. ½" hardwood gussets reinforcing internal bonding of upper centering bulkhead to airframe. Band of carbon/Kevlar fabric laminated to upper midbody airframe to toughen against impact and zipper damage.
3) Frangible components – Styrofoam skins applied to fin cores are for cosmetic appearance, and may be subject to flight damage and repair without affecting flightworthiness.

Interior layout of components:

1) Detail view of upper midbody recovery compartment with structural and mounting members
(This section has been modified significantly, as described later in this document.)

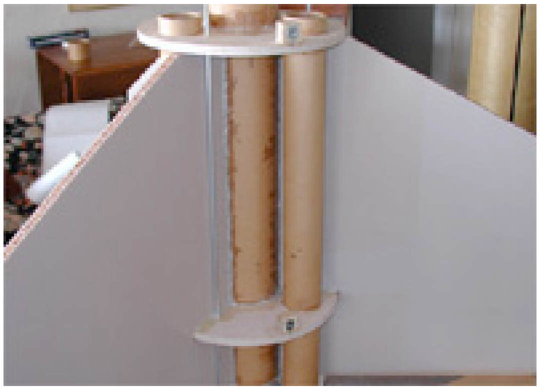


2) Detail view of lower payload section with structural and mounting members



Photos documenting construction details and hidden interior components (for more photos and details, see http://www.physics.hmc.edu/GL/WAC/gindex.html):

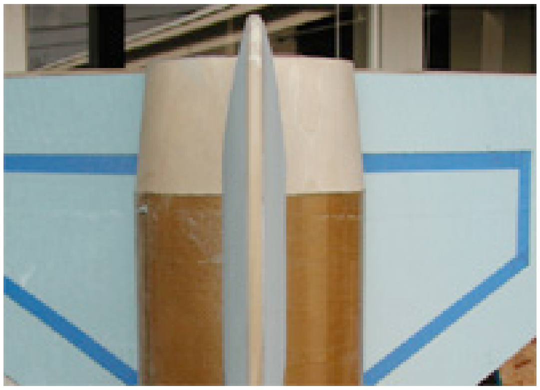

(a) motor mount assembly with fin core


(b) fins glued and filleted to motor mounts


(c) construction of boat tail assembly


(d) completed boat tail and fin can


(e) internal view of reinforced joint coupler with compression bar


(f) fins after application of foam skins

(g) internal view of midbody recovery bay with drogue piston, U-bolt and ribs

(h) internal view of payload ejection piston with bulkhead and hardware

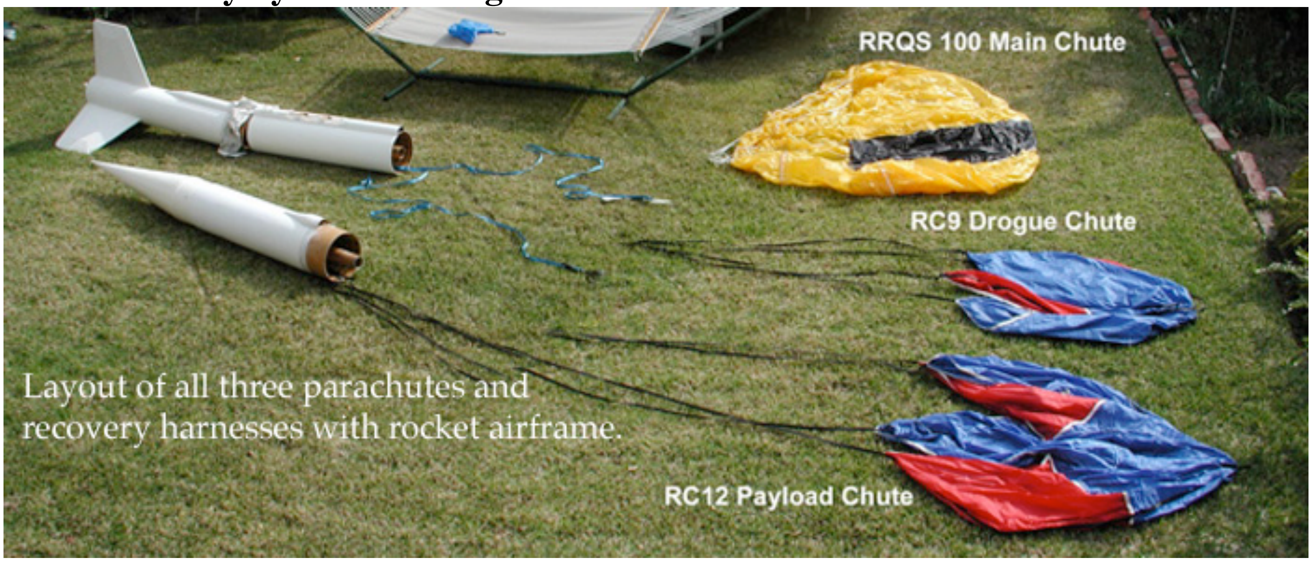
(i) application of carbon/Kevlar reinforcement band to upper midbody airframe

(j) construction of electronics bays in external conduit

(k) rear view of complete lower and midbody sections with primer applied

(l) front view of sections with primer applied

IV. Recovery Systems Package



Layout of all three parachutes and recovery harnesses with rocket airframe.

Description of recovery system operation

1) Deployment Sequence
The deployment sequence consists of three main events: apogee separation, drogue deployment, and main deployment. Each of these three events is triggered by two independent and redundant electronic systems. Apogee separation is effected by a 5 gram black powder charge. The charge contains two electric matches each connected to the apogee circuits of the two barometric altimeters. Apogee charge separation causes the nose cone/payload section to separate from the booster airframe with its own parachute, and its descent is completely passive from that point onward.

About one second after apogee separation, the booster drogue chute is ejected by the drogue piston, which is energized by one of two half-gram black powder charges and electronic matches. The drogue piston is fired by the second channel of the Co-Pilot altimeter, which is configured as an apogee backup channel, triggering one second after the first channel. Redundant backup for the drogue is provided by the PET timer, which begins timing after apogee separation causes opening of a pull-pin circuit.

The RRQS 100 main chute is designed to bring down the booster section gently after the drogue has stabilized the descent. The period of pendulum swinging under the drogue chute should be approximately 7 seconds, so the main is set to deploy at 12 seconds after drogue deployment. This event is controlled by the second channel of the PET timer which started counting at apogee pull-pin. The timer fires an electric match in the Tether pyro release connecting the drogue to the main U-bolt (see below). Upon release, the drogue and harness pull free of the airframe, connected only to the apex of the main chute by a light nylon cord. The main is pulled from its bay in the upper midbody and extends and inflates. Backup triggering of the main chute event is provided by a second electric match connected to the second channel of the Perfectflite altimeter, set to fire at 1700 feet AGL.

2) Mounting and harness connections
As described in the construction package part of this document, The payload section and midbody section each include a U-bolt hard attachment point, affixed to a main plywood centering

ring/bulkhead. In the case of the payload section, this is simply the single point of attachment of the payload parachute, without further complication. Attachments to the other U-bolt are however, somewhat more complex.

Two 15 ft. long by ¾" wide tubular nylon harnesses are attached to the midbody U-bolt. One is attached directly, by means of a heavy-duty stainless steel quick link. This harness is in turn connected to the main parachute, and is the point of recovery attachment during the terminal phase of the flight between main release and touchdown. The second harness is attached indirectly via the Tether pyro release mechanism. This connection absorbs the shock of initial drogue deployment and deceleration. Upon firing of the pyro release, this hard connection is severed and the harness is pulled free by the drogue chute. Attached to the now-free end of the drogue harness is a lightweight nylon cord which connects it to the apex of the stowed main chute. As the drogue harness pulls away, it pulls the main chute, top end first, from its stowed position in the recovery bay. As the main chute inflates, the rocket slows to its terminal descent velocity and the now-deflated drogue chute trails off to the side, still attached to the inflated main.

3) Parachute enclosures

As illustrated in the construction package, the recovery compartment is divided by walls into three subcompartments. These three compartments contain (a) the drogue parachute, shroud lines and deployment piston assembly, (b) the main chute along with its shroud lines and harness, and (c) the pyro release, attachment hardware and the remaining attachment harnesses/lines that run into this compartment from the others. Being physically separated from the black powder charges in both the separation cannon and the drogue piston, the parachute are all protected from heat or scorching without the need for wadding of thermal protection blankets. Closure retention of the recovery system compartment is provided by a conventional friction fit of the payload section and the rest of the airframe.

4) Compartment venting

The volume of the recovery compartments is vented to outside pressure by three 3/16" holes drilled into the payload section airframe between its bottom edge and the plywood bulkhead that forms the floor of the payload section. These vents serve to prevent premature separation due to pressure trapped in the bay. In addition to this venting, the payload coupler has six large ½" holes which are revealed as the joint starts to separate, and provides additional pressure equalization.

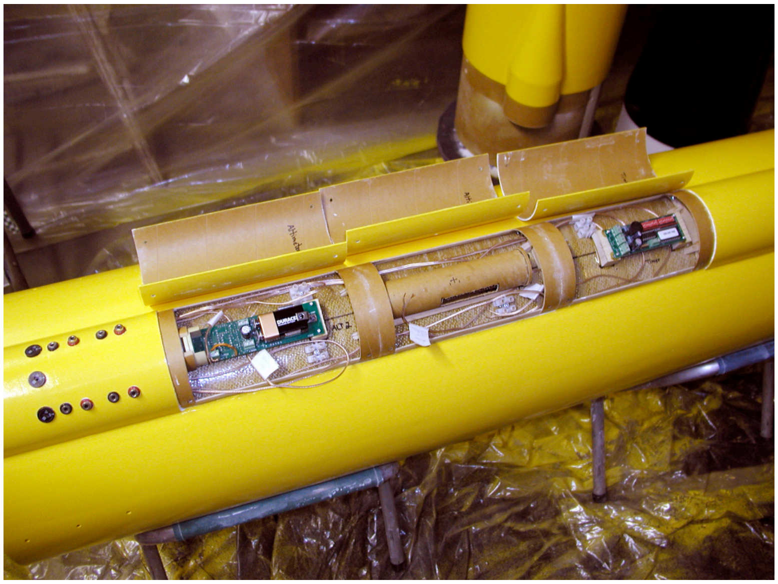
5) Descent rate estimates

The rocket is returned in two pieces, each of which requires a descent rate estimate. The payload/nose cone section will have a mass of 8.5 kg, and descend on an RC-12 parachute. Based upon the measured descent rate of 27 ft/sec on a previous flight with the same parachute and a 16 kg payload, this segment's descent rate is estimated to be between 15 and 19 ft/sec. (The payload parachute was changed to an RRQS 50, which should have a descent rate of 14 ft/sec.)

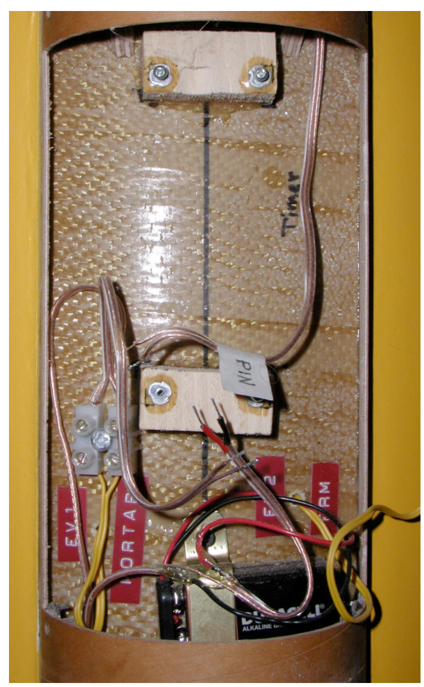
The remaining booster airframe and fincan have a descent mass of 25.8 kg. Without previous flight experience with the RRQS 100 parachute, the manufacturer's specifications indicate an expected descent rate of between 12 and 16 ft/sec. Both of these descent rates should be within the range of acceptable and safe values.

6) Flight Electronics

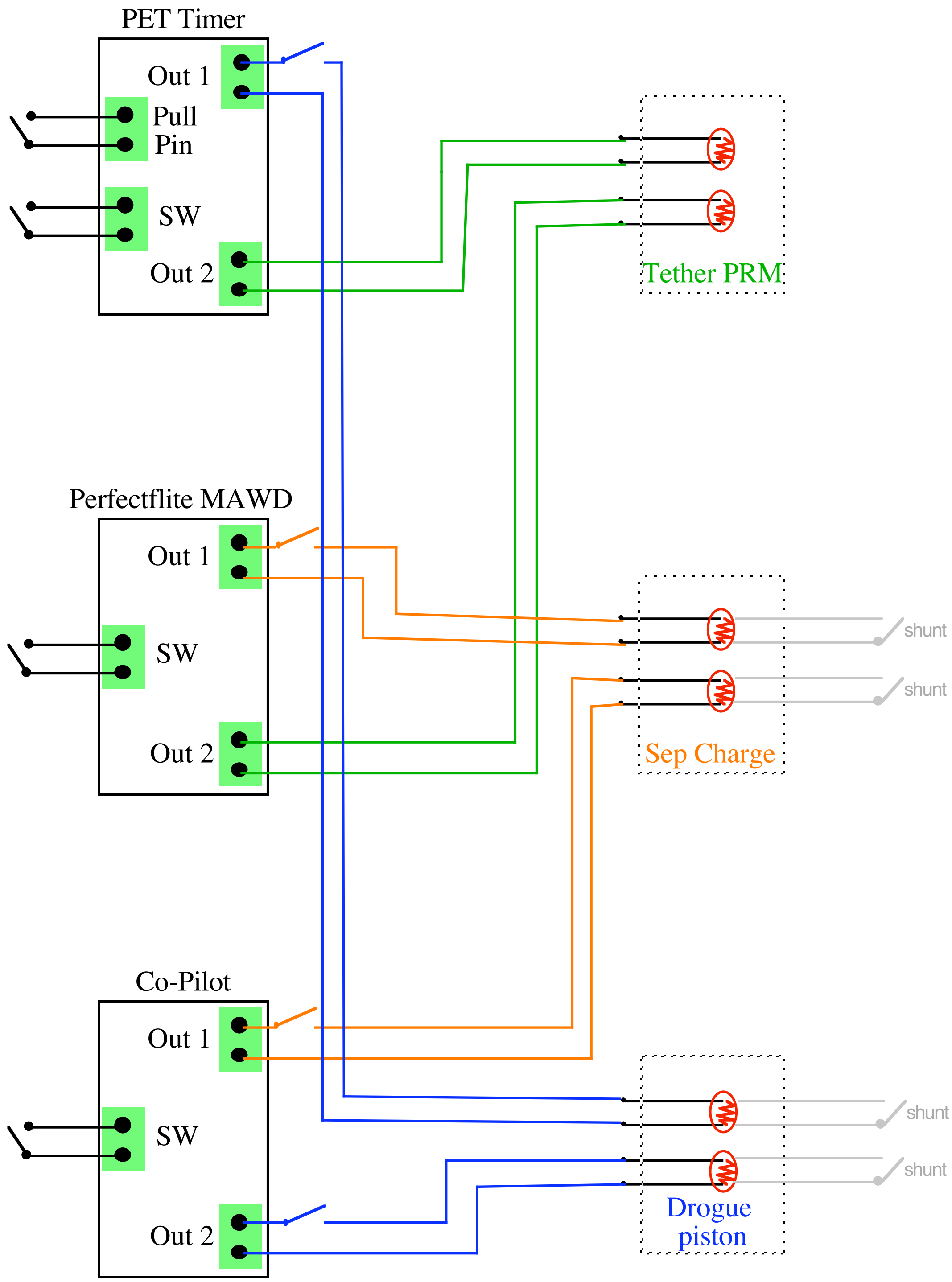
The flight electronics and wiring are contained in three separate compartments within the scale conduit running along the side of the midbody airframe. These are shown in the photo below. The compartments house, from left to right (aft to fore), the Co-Pilot barometric altimeter, the Perfectflite recording altimeter, and the PET event timer. At far left (aft end) is a fourth compartment housing the arming switches and shunts, so that control of all the avionics is in this common area.



The wires for the matches reach the compartments via pass-through holes from the recovery bays. Switch and shunt wiring pass along the sides of the compartments as shown in the detailed views below.



On this page is the schematic wiring diagram of the flight electronics. The configuration is designed to provide two independent and redundant triggers for each flight event. Total failure of any one of the three electronics is completely backed up. The PET timer is triggered by pull-pin initiation when the separation charge fires at apogee. The two altimeters are triggered by barometric sensing of altitude change (no g-switches are used in this system). The new design also incorporates external break switches on each of the four shunted charge matches for added safing capability.



V. Stability Evaluation

A) *Launcher description*:
A heavy-duty C-rail and custom machined Delrin rail buttons will be used. The launch system will be courtesy of ROC member Ron McGough, and includes the necessary hybrid motor ground support equipment for a Hypertek launch. Depending on the status of work on McGough's launch system, the rail length will be either 12 or 20 feet, either of which should be adequate for the anticipated liftoff speed (in the absence of high winds). (The 20 ft. rail was used on the first flight.)

B) *Center of Pressure*:
The center of pressure for flight stability was calculated manually using the Barrowman method (valid for subsonic flight at low angles of attack). The following table summarizes the the calculation for three fins-tube-nose cose-tail cone:

	C_N	*X (inches)*
Nose Cone	2.0	31.6
Tail Cone	-0.44	185.3
Fins	14.07	174.5

$$X_{CP} = \frac{\sum C_N X}{\sum C_N} = \frac{2437.1}{15.63} = 155.9 \ inches$$

C) *Aft CG limit*:
Based upon a 1.5 caliber stability margin, the maximum allowed CG distance is 138 inches from the nose. Pre-launch checklist will verify this condition is met. Post-construction measurement of component masses and locations yields an estimated flight CG position of 126.5 inches; this is a very ample stability margin of about two and a half calibers. (First flight verified ample stability, with a slight tendency to weathercock.)

VI. Expected Flight Profile

Launch mass: 40.8 kg (90.0 lb)
Motor: Hypertek M1001 (5478 cc hybrid); Total impulse 9835 N-sec; NAR/Tripoli certified
Estimated drag coefficient: 0.55 (based on cross sectional reference area)
Launch rail velocity: 17.4 m/sec (57 ft/sec)
Maximum velocity: 118 m/sec (386 ft/sec, Mach 0.34) @ 7.1 seconds
Maximum altitude: 1085 meters (3560 ft) @ 17.1 seconds
Actual flight results: 1157 meters (3796 ft) @ 17.2 seconds
Maximum acceleration: 2.6 g's @ 0.1 seconds
These calculations were made using CompuRoc version 2.0, assuming a launch elevation of 3000 ft and air temperature of 88°F.

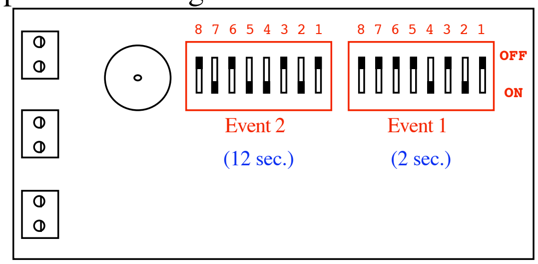
VII. Pre-launch Checklist

A) *Equipment List*
❒ - Motor grain, O-rings and fittings
❒ - Assembly screwdrivers and Allen wrenches
❒ - Volt/Ohm meter
❒ - Motor retention clips, rail buttons, assembly screws, shunts
❒ - Safety glasses
❒ - Table, chairs, EZ-Up, and rocket support stands

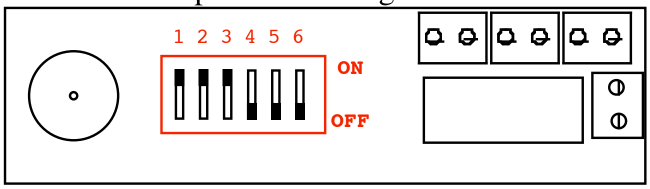
B) *Safety Practices*
❒ - Hazardous items: 5 gram sep charge, 0.5 gram drogue charges (2), 0.2 gram pyro release charge; transport to launch site pre-assembled in non-static container
❒ - Precautions: install shorting shunts before installation or hookup of any pyro charges; verify all switches in "off" position; clear non-essential personnel from rocket vicinity during installation

C) *Motor Preparation*
❒ - Have ready zip cord igniter wire and cable ties for fill stem
❒ - Assembly of Kline valve, bell, grain and vent tube
❒ - Install motor and retention straps with vent tube in visible location

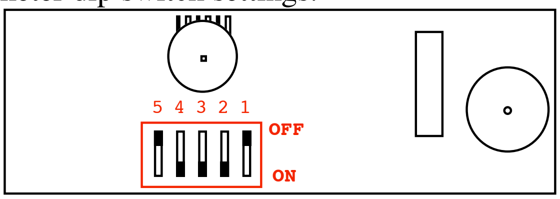
D) *Electronics Preparation*
❒ - Verify safe status; switches and shunts in position
❒ - Check new batteries for voltage and install
❒ - Set/verify PET Timer dip switch settings:



❒ - Set/verify miniAlt WD altimeter dip switch settings:



❒ - Set/verify Co-Pilot altimeter dip switch settings:



❒ - Install and secure all three electronics packages
❒ - Attach all switch and device wires to electronics
❒ - Clear area, remove shunts, check continuity
❒ - Return all switches and shunts to safe status

E) *Pyrotechnics*
❒ - Check resistance of all electric matches prior to installation
❒ - Verify safing of all charges both before and after connecting to electronics

F) *Recovery System*
❒ - Inspect all parachutes, shrouds and harnesses for condition and tangles
❒ - Attach pyro release mechanism and drogue harness to U-bolt; foam cushion around pyro
❒ - Stow drogue harness and shroud lines, followed by drogue canopy in mortar
❒ - Attach main harness to U-bolt and apex line to drogue harness above the pyro
❒ - Stow main harness, shrouds followed by canopy in main compartment with apex on top
❒ - Attach apex line to top of main chute; cover main with paper cover
❒ - Fold and attach payload chute to upper U-bolt; pack loosely on top of recovery bay
❒ - Attach pull-pin line from payload section
❒ - Mate payload section and check friction fit

G) *Final Assembly*
❒ - Mate Fin can to midbody and torque joint screws to produce secure friction mating
❒ - Verify electronics still safed
❒ - Install rail buttons (3) and check alignment
❒ - Verify CG location

VIII. Launch Checklist

❒ - Equipment list - Ladder, stethoscope, checklists, launch pad supplies and tools, support stands
❒ - Install rocket on rail and elevate to vertical
❒ - Install igniter and fill stem

Arming
❒ - Remove all shunts
❒ - Power on electronics and verify normal test tones:
PET Timer: 3 beeps (repeat)
miniAlt WD altimeter: 0 (mach delay), 1700 (main alt.), ????(last flight alt.), 3 beeps (repeat)
Co-Pilot altimeter: 3 beeps (repeat)
❒ - Verify connection and integrity of oxidizer fill and ignition systems
❒ - Verify readiness of flight witnesses and photographers
❒ - Notify LCO and range personnel of flight readiness

IX. Post-flight Checklist

❒ - Gather and secure deployed parachutes
❒ - Check for unfired drogue charge; if present, install shunt
❒ - Read out and record altimeter reports
❒ - Power off all electronics

X. Contingency Checklist

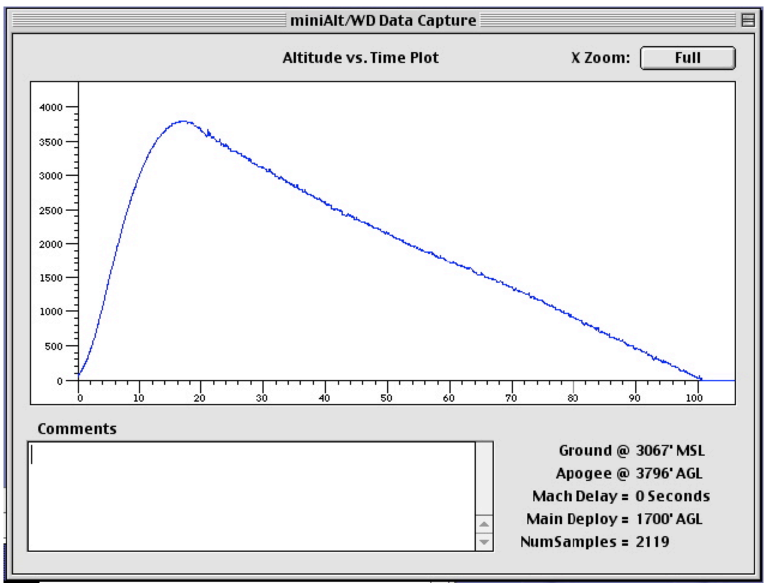
In event of launch abort/misfire or crash landing
❒ - Shunt and power down all electronics
❒ - Vent oxidizer and remover igniter (if applicable)
❒ - Note operating time on flight batteries if flight recycling is anticipated

XI. First Flight Results and Modifications

1) First Flight Outcome

The first flight and certification attempt was carried out on the afternoon of 11 June 2005, during ROC-Stock XXI at Lucerne Dry Lake. Launch from Ron McGough's trailer launcher was delayed by leak problems with the hybrid GSE, which had sustained damage from another launch earlier in the day. Once the hybrid fill problems were solved, the preparations for launch proceeded normally, following the nominal checklist.

The powered phase of the flight was nominal, with the Hypertek M1001 burning as expected and producing the expected flight profile (see graph below). Light winds in the vicinity of 5-10 mph produced slight weathercocking but did not cause any problem. As shown in photo (c) on the following page, the apogee deployment sequence executed exactly as planned. The separation charge fired, moving the nose section clear of the booster and descending on its parachute. A couple of seconds later, the drogue piston fired and deployed the drogue chute. The drogue inflated and relatively gently reoriented the falling booster from nose-first to tail-first descent.



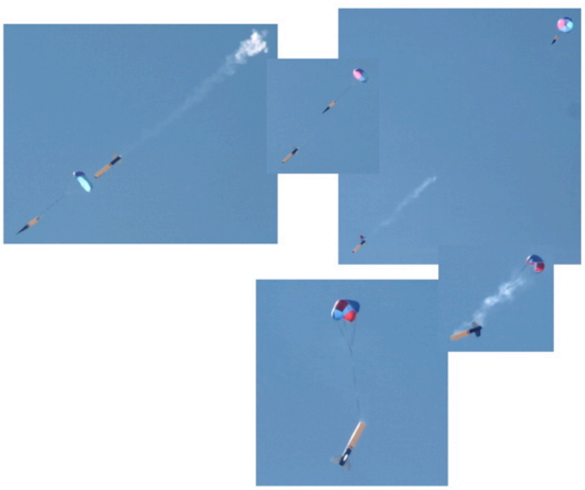
At this point the only (and critical) anomaly of the flight occurred. The Tether pyro release fired on cue to allow the drogue to pull out the main, but only after the Kevlar piston strap had wrapped itself around the drogue shock cord just above the foam cushion that was attached to the shock cord to prevent zippering damage on deployment. (See photo (d) on the next page.) This accidental retention proved strong enough to support the weight of the booster and prevent the main chute from being pulled from its bay.

The resulting drogue-only landing occurred at a speed of approximately 45 ft/sec, which in addition to violating the requirements for Level 3 certification, caused damage in two parts of the rocket. As seen in photo (f), the lowermost inch or so of the honeycomb core of one of the fins suffered crushing damage. (Note that this damage was cosmetic and not structural, so that the rocket could have been reflown if this has been the only damage.) More serious was the damage to the upper end of the midbody when it slapped the ground (photo (e)). Although the Kevlar-carbon cladding was mostly intact, the inner phenolic layers shattered badly doing extensive damage to the recovery bays. This section of the rocket would have to be replaced.

The piston tangling problem is easily avoided in the future by simply eliminating the strap and making the piston expendable. However strengthening and reliability of the upper midbody are also addressed in a redesign, which is described in the following section.

(a) Preflight photo

(b) Launch photo



(c) separation and deployment sequence

(d) main deployment fouled by piston strap

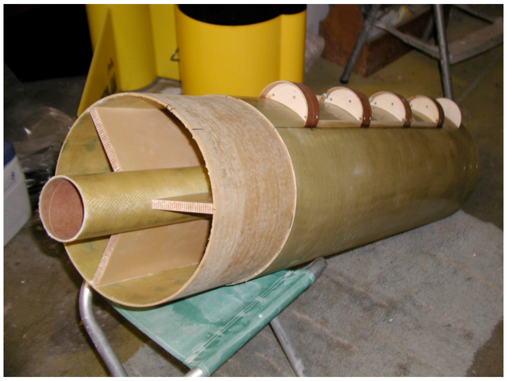
(e) landing site of booster section

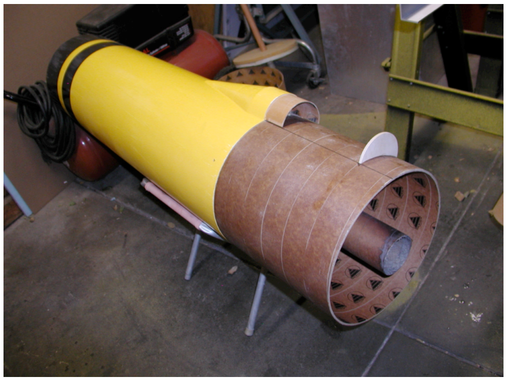
(f) fin damage due to hard landing

2) Repairs and Modifications
The entire midbody section needed to be replaced, since repair of the upper end damage was deemed not feasible. The decision was made to somewhat alter the design in order to (a) minimize the possibility of future recovery system tangles, and (b) harden the structure against damage from normal landing impact. As mentioned in the previous section, the tangle problem would be eliminated by making the drogue piston untethered and allowing it to fall free after deployment.

The strength issue was addressed by moving the location of the nose-midbody coupler from the nose section to the upper end of the midbody (for reference, see the diagrams on pages 5 and 6). The significance of this change is that it allows the internal honeycomb spacer ribs to extend the full length of the recovery bay, thereby providing rigid internal support all the way to the end of the midbody section. This modification is shown in photo (a) below. In addition to the supporting ribs, the new coupler has been internally laminated with a layer of Kevlar fabric for added strength.

The shift in location of the coupler meant that a corresponding section of outer airframe tube needed to be removed from the midbody and appended to the nose section, to form a mating pair with the same overall assembled dimensions. This extension of the nose section is shown in photo (b). The fin trailing edge repair is shown in photo (c). The damaged region of honeycomb core was cut away and a new section spliced in with pieces of 0.02" G-10 sheet. The resulting repair is as strong as the original material. The overlying foam and skin materials were replaced, completing the repair.


(a) modified midbody coupler and recovery bays


(b) extension of nose section airframe


(c) replacement of crushed fin edge