Level Three Certification Project – October 25, 2008

Project Name : Big Fellow Rocket

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Advisors: **Gerald Meux – L3CC**
Maurice Bertrand

FOREWARD: Thanks and Appreciation

To my wife and daughters, for their un-ending patience with my crazy hobby.

To Gerald Meux and Moe Bertrand for their support, oversight and mentoring during this six month long undertaking.

To my rocket buddies in the Superstition Spacemodeling Society for putting up with my endless questions.

To Kent Burnett of Giant Leap for his assistance in sizing the recovery gear.

To Frank Uroda of Public Missiles for enduring my airframe questions.

To Jim Amos of Missile Works for his assistance with altimeter applications.

I) Introduction:

This level three certification project consists of a 7.75” Diameter x 136.25” Long fiberglass over phenolic airframe. The fiberglass nosecone is a 5:1 ogive design. The rocket empty weight is 58 Lb - 3 Ounces with a center of gravity located at 80” from the tip of the nose cone. The center of pressure is located at 100.75” from the tip of the nose cone. The motor mount is capable of loading up to 98mm x 48” Long re-loadable motor casings. It is a four swept fin design with upper and lower payload bays for drogue and main parachute recovery gear. Recovery events are initiated by redundant electronic barometric controllers. The altimeter bay is large enough to accommodate a video camera system in the future.

Certification Motor:	**Aerotech M1315W**
Projected Max Altitude:	**4875 Ft AGL (simulated)**
Drogue Deployment:	**Apogee**
Main Deployment:	**2000 Ft AGL**

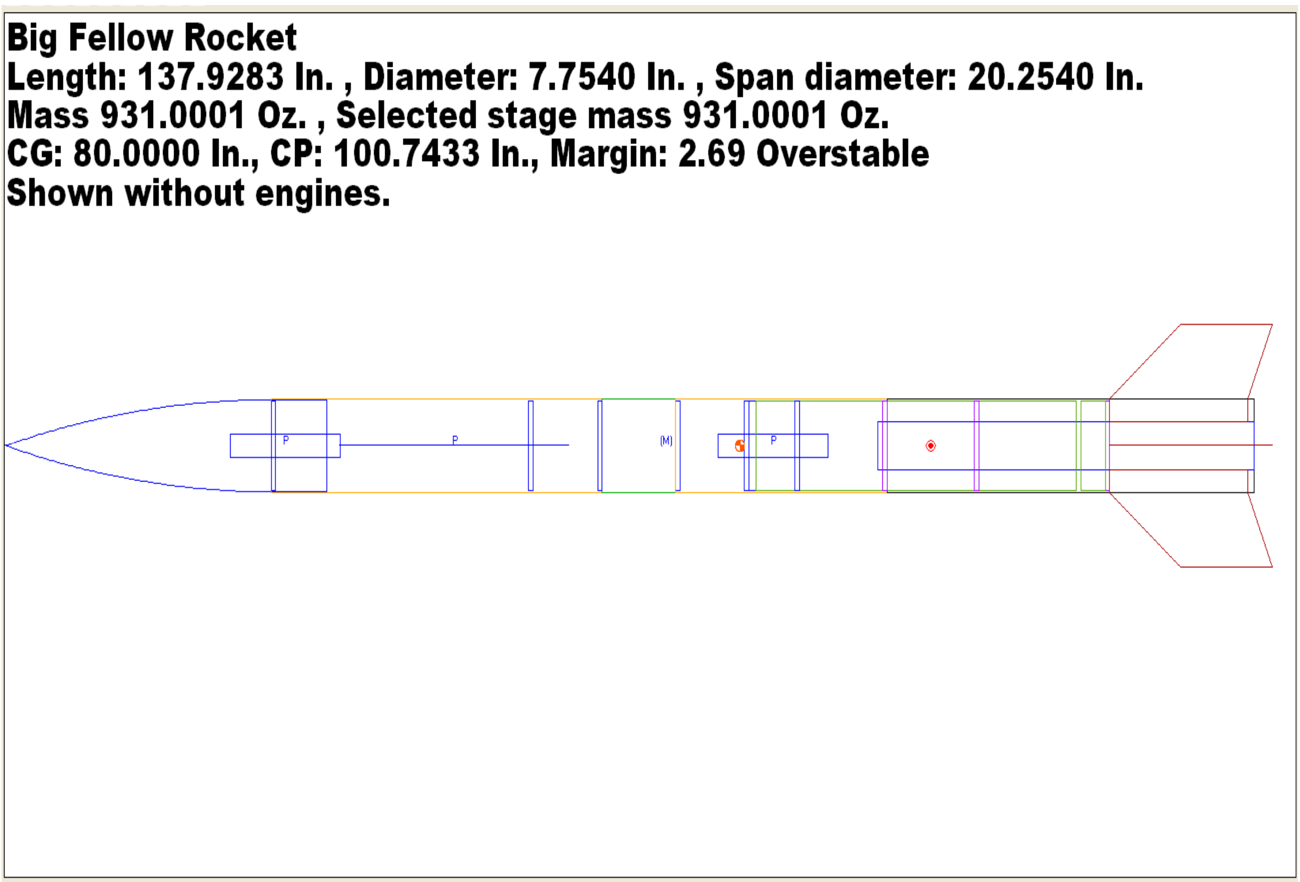


Figure 1 – Empty Weight

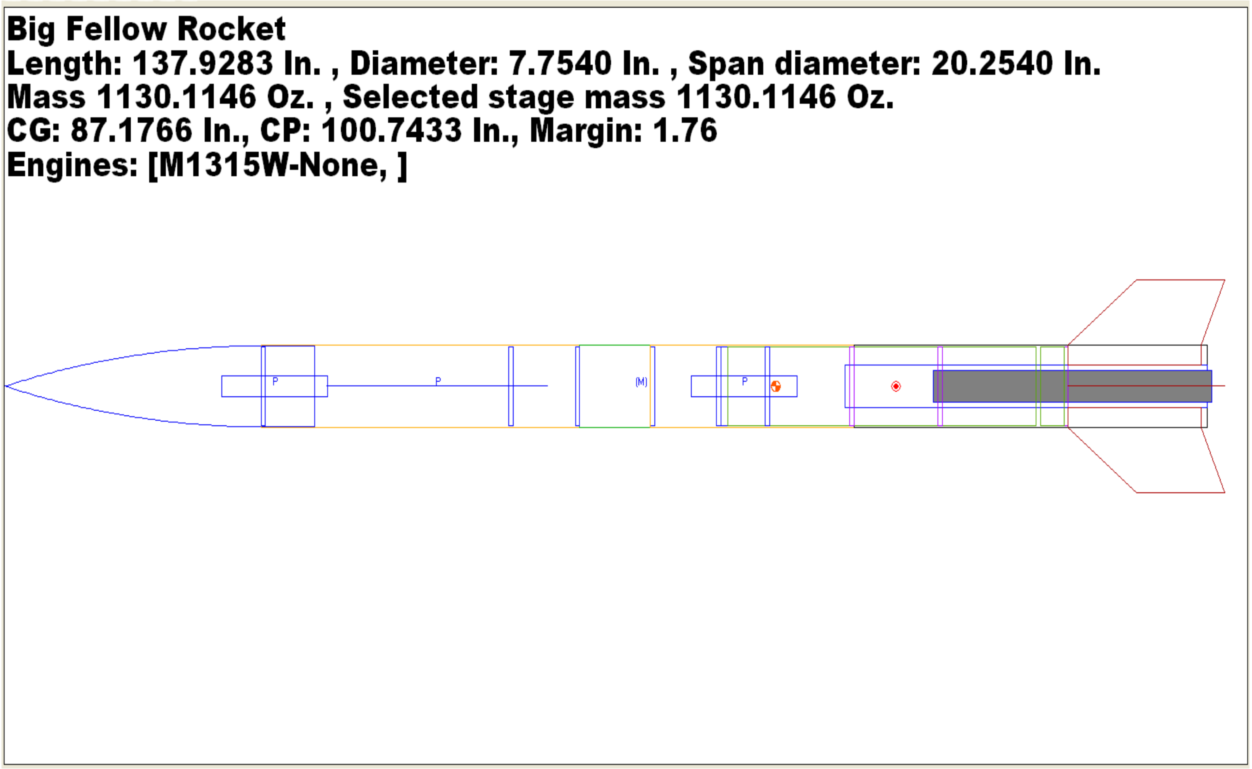


Figure 2 – Loaded Weight with Aerotech M1315W

II) Rocket Dimensions:

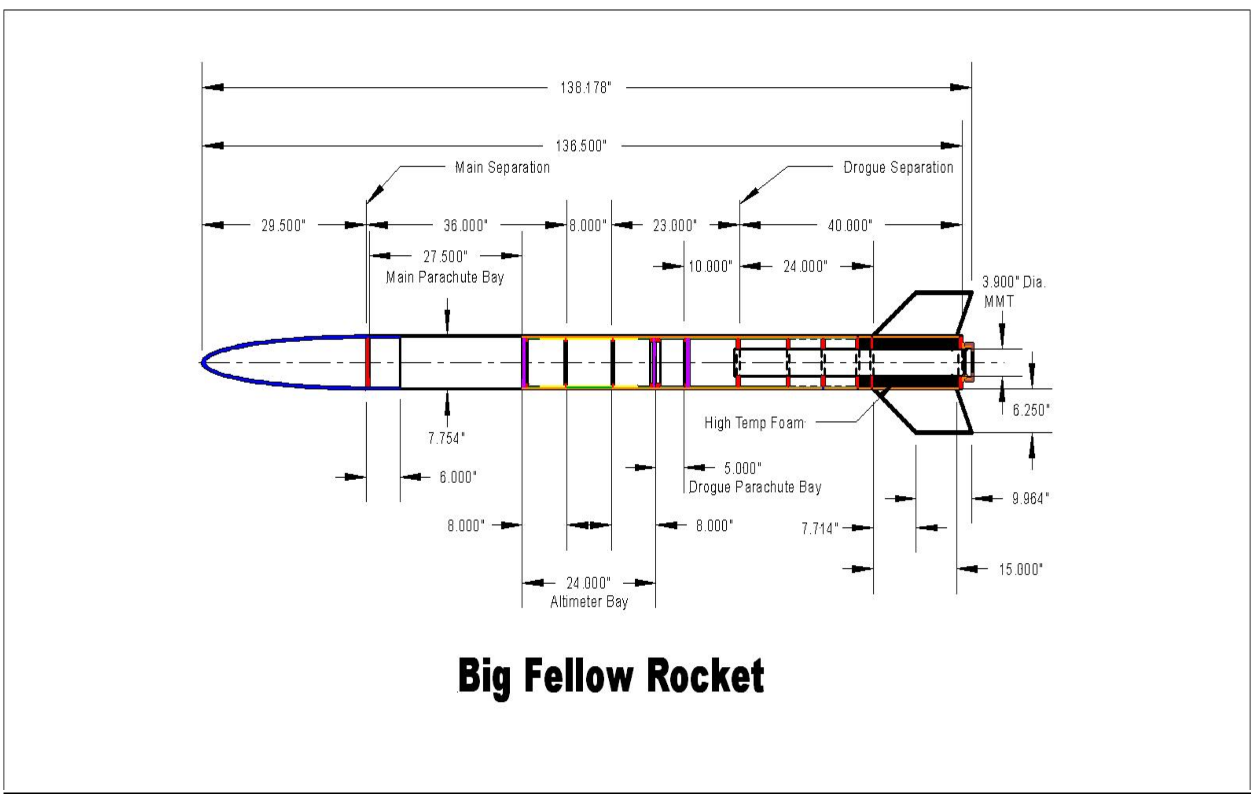


Figure 3 – General Dimensions

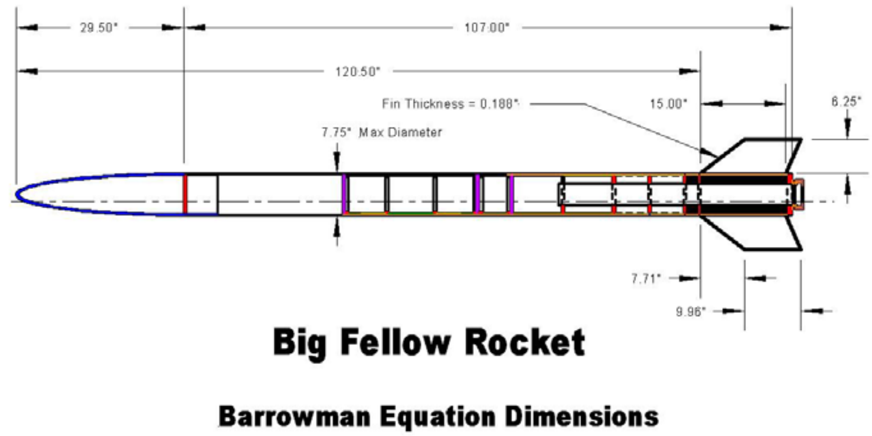


Figure 4 – Barrowman Equation Dimensions

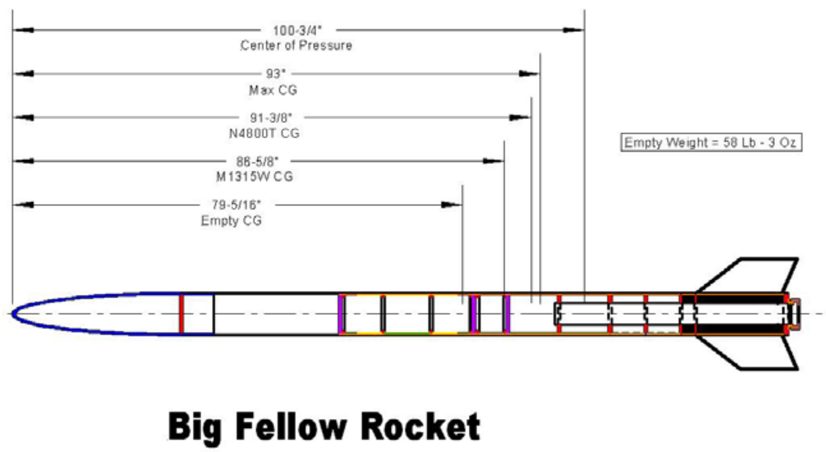


Figure 5 – Center of Gravity and Pressure

III) <u>Construction Materials</u>

A) Overview

The nose cone is a Public Missiles fiberglass 5:1 ogive unit for a 7.5” diameter airframe. The nose cone bulkhead is fabricated from ½” thick Russian birch plywood and is recessed 5 ½” to accommodate the 72” pilot parachute. This bulkhead and the inner surface of the nosecone shoulder are reinforced with 2 layers of 6 oz fiberglass cloth bonded with epoxy. The outer airframe is Public Missiles phenolic tubing with exterior reinforcement consisting of two layers of 6 oz fiberglass cloth bonded with epoxy. The airframe aft of the front altimeter bay bulkhead back to the leading edge of the fins is triple walled. Sections of the altimeter bay and drogue bay airframe fastener bands are quadrupled walled for additional strength. All bulkheads, centering rings and retaining rings are fabricated from ½" thick - 9 ply Russian birch plywood. The aft centering ring / motor retention ring is fabricated from ¾" - 13 Ply Russian birch plywood. The 3/16" thick G-10 fiberglass fins are attached to the 98mm motor mount tube with two layers of 6 oz fiberglass cloth bonded with epoxy. The fins are also bonded to the interior of the airframe with one layer of 6 oz fiberglass cloth laid in epoxy. The fins are bonded to the airframe exterior with ¼" radius epoxy putty fillets for additional strength. The annulus area along the fin compartment between the motor mount tube and the airframe interior is filled with high temperature two part expanding foam for additional rigidity.

B) Airframe Materials

1) Airframe Tubing – Public Missiles phenolic tubing re-enforced with two external layers of 6 oz fiberglass cloth bonded with epoxy.
2) Fins – Public Missiles 3/16" thick G-10 fiberglass.
3) Centering Rings – ½" thick 9 ply Russian birch plywood. The aft centering ring / motor retainer mounting plate is ¾" thick 13 ply Russian birch plywood.
4) Launch Lugs – 3 Public Missiles Urethane rail guides for 8020 Corp. 1515 rail.
5) Reinforcement Materials – 6 oz fiberglass cloth bonded with epoxy.
6) Fin Can Foam - Giant Leap High Temperature two part expanding foam.
7) Adhesives – Sticky Stuff SS-27 Resin with SS-40 Hardener. The launch lugs are attached with standard set JB Weld. Exterior fin fillets are Sticky Stuff Wonder Putty.
8) Nosecone – Public Missiles 7.5", 5:1 ogive fiberglass nosecone.

C) Construction Techniques

1) Fin Mounting Method – The G-10 fiberglass fins are attached to the exterior of the 98 mm motor mount tube with two layers of 6 oz fiberglass cloth bonded with epoxy. All associated fin surfaces were roughed up with 120 grit sandpaper and then cleaned with de-natured alcohol prior to bonding. The fins were bonded to the airframe interior with one layer of 6 oz fiberglass cloth bonded with epoxy. The fins were also attached to the airframe exterior with ¼" fillets of Wonder Putty.
2) Reinforcement Areas – The altimeter bay is completely triple walled. The center section of the altimeter bay and airframe fastener areas are quadrupled walled. The external tube is Public Missiles phenolic tubing wrapped with two layers of 6 oz fiberglass cloth bonded with epoxy. The interior reinforcing tubes are Public Missiles phenolic coupler tubing laid in epoxy. The third layer of interior tube was split axially to fit inside of the second layer of coupler tubing as required and then laid in epoxy. The aft airframe (drogue parachute bay) is also triple walled. The booster airframe

is triple walled from the front of the booster airframe to the leading edge of the fin compartment. All bulkheads and centering rings are captured between inner airframe sections for additional rigidity. The booster section coupler is double walled. The fin can area is fiberglass reinforced and filled with two part high temperature expanding foam. The fin can bulkhead assembly is connected to the booster airframe coupler bulkhead by four ¼-20 all thread rods to distribute the recovery shock load back into the booster airframe.

D) Interior Layout

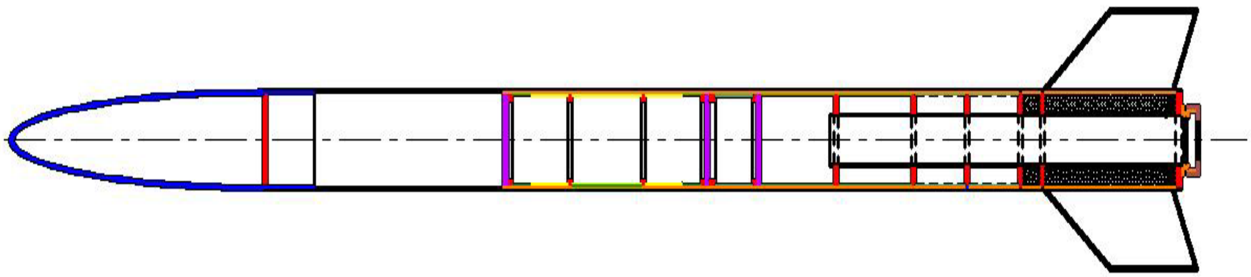


Figure 6 – Interior Layout

E) Construction Photographs

Coupler Length Cut

Coupler Sizing

Coupler Sizing

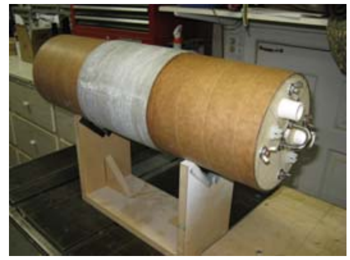
Nosecone Bulkhead

Airframe/Altimeter Bay Fasteners

Altimeter Bay Components

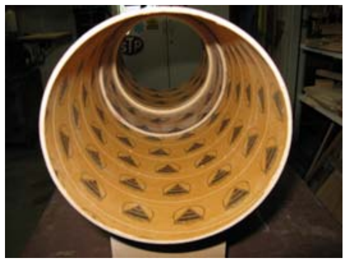
Altimeter Bay Interior

Altimeter Sled



Altimeter Bay Assembly

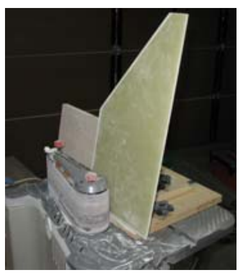
Aft Airframe Stiffener



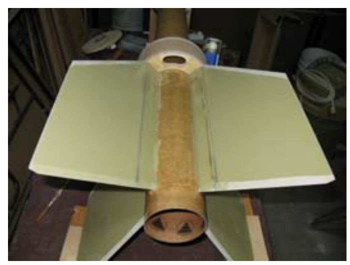
Aft Airframe Interior

Booster Coupler Components

Booster Coupler Interior



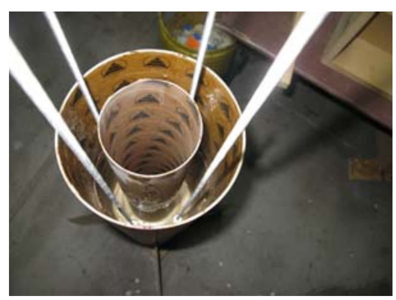
Fin Beveling Jig



Fin Can Assembly

Fin Can Bulkhead

Fin Can Tension Rods



Booster Interior

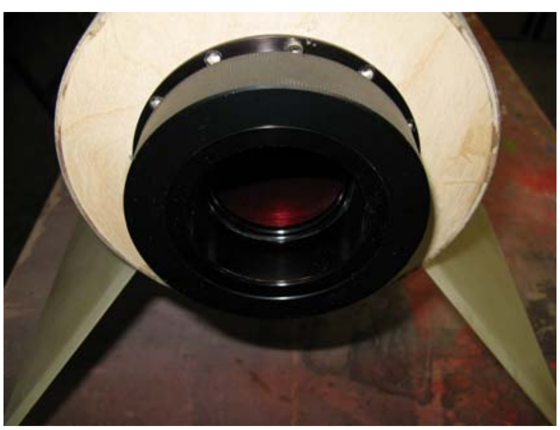
Foamed Fin Can

Booster Assembly

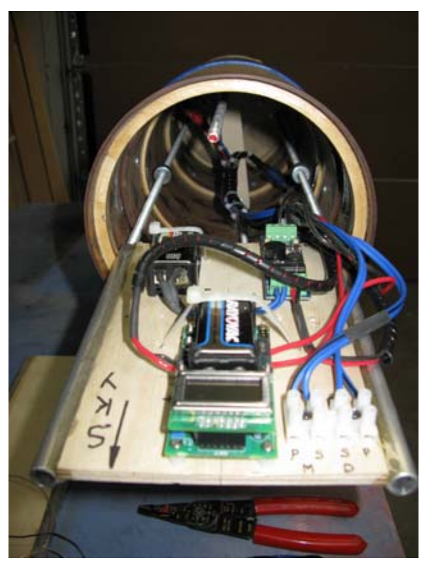
Fin Fillets

Triple Rail Guide

Dr Rocket 75/6400 Motor Casing and Adapters



75/6400 Casing Installed



Completed Altimeter Sled

IV) Recovery System

A) Operational Description

1) The recovery sequence starts with the deployment of a 48" drogue parachute at flight apogee. This is followed by the deployment of a 72" pilot attached to the apex of the 150" main parachute at 2000 Ft AGL.
2) There are three main sections to the Big Fellow Rocket. The nosecone, the airframe assembly and the booster section containing the rocket motor assembly. The nosecone is connected to the fore airframe assembly by 45 lineal feet of 1" tubular nylon shock cord. The aft airframe assembly is connected to the booster section by another 45 lineal feet of 1" tubular nylon shock cord. The shock cords have pre-sewn loops at both ends to facilitate attachment to the 3/8" diameter U-bolts located on all attachment bulkheads. The shock cord loops are connected to the bulkhead U-bolts with 3/8" diameter quick links.
3) The drogue parachute compartment is 5" long x 7 ½" diameter and is located in the aft airframe. The main parachute compartment is 22" long by 7 ½" diameter and is located in the fore airframe.
   a) There are six 2-56 nylon screw shear pins restraining the drogue parachute compartment. There are four 2-56 nylon screw shear pins restraining the main parachute compartment.
   b) All parachute assemblies are protected from the hot ejection charge gasses by two layers of Kevlar pads.
4) The drogue parachute compartment is vented with a 5/32" diameter hole located just in front of the leading edge of the booster coupler assembly. The main parachute compartment is vented with a 5/32" diameter hole located in the shoulder of the nosecone.
5) Parachute Decent Rates
   a) The decent rate for the drogue parachute was estimated using a decent rate calculator, version 3.3 by Jordan Hiller. This calculator can be found at http://www.onlinetesting.net/cgi-bin/descent3.3.cgi. For a rocket weight of 1110 ounces and a target decent rate of 60 ft / sec, the data was interpolated and yielded a Sky Angle parachute size of 48". According to Ken Burnett of Giant Leap Rocketry, TAC-1 parachute decent rates are similar to those of Sky Angle parachutes.
   b) The decent rate for the main parachute was provided by Giant Leap Rocketry. According to their published online data, the TAC-9C parachute will yield a decent rate of approximately 16 ft / sec for rockets up to 70 LBs (1120 ounces) in weight.

B) Component Description

1) Control Devices
   a) Primary Controller – Olsen FCP-M2
   b) Backup Controller – Missile Works RRC2-Mini
   c) Sensing Method – Barometric Pressure
   d) Power Sources – Two independent 9 VDC Batteries
   e) Safe and Arm Controls – Schurter 2 position voltage selector switches.
   f) Mounting Method – machine screws with nylon standoffs to altimeter sled.
   g) Wiring Schematic (see Appendix A)
   h) Altimeter Bay Static Port Sizing

Bay Volume = $V_b = (\pi/4)(D_t^2)(L)$

Where: D_t = Altimeter Bay Inside Diameter (in) = 7.5"
L = Altimeter Bay Inside Length (in) = 24"

Therefore: $V_b = (\pi/4)(7.5)^2(24)$
$\underline{V_b = 1060.3 \text{ in}^3}$

$\underline{\text{For } V_b \geq 100 \text{ in}^3}$

$D_s = 2 * \text{SQRT} \{[(V_b/100)(0.04908)]/\pi\}$

Where D_s = Diameter of a single static port (in)

Therefore: $D_s = 2 * \text{SQRT} \{[(1060.3/100)(0.04908)]/\pi\}$
D_s = 0.814"

$D_n = \text{SQRT}[(D_s/N)/\pi]$

Where D_n = Diameter of N (number) of static ports
N = 6

Therefore: $D_n = \text{SQRT}[(0.814/6)/\pi]$
$\underline{D_n = 0.208"}$ (use 7/32" dia drill x 6 places)

2) Parachutes
   a) Drogue Parachute – Giant Leap TAC-1-48
   b) Main Pilot Parachute – Giant Leap TAC-1-72
   c) Main Parachute – Giant Leap TAC-9C
   d) Main Parachute Deployment Bag – Giant Leap TAC-9C Bag

3) Risers

a) 20’ and 25’ long x 1” tubular nylon straps connected with a 3/8” diameter quick link for both the drogue and main parachutes. Breaking strength = 4000 LBs Test per MIL(C)SPEC 5625.
b) Attachment Method – pre-sewn loops.
c) Drogue parachute is connected one third of the way, closest to the booster section, between the aft airframe and the booster section.
d) Main parachute is connected one third of the way, closest to the nosecone, between the nosecone and the fore airframe assembly.

4) Mounting Hardware
   a) Mounting Points – nosecone, fore / aft altimeter bay bulkheads and booster section fore bulkhead.
   b) Quick Disconnect Links – 3/8” Quick Links
5) Pyrotechnik Devices
   a) Quantity = 4 (2 drogue, 2 main)
   b) Bridgewire – electric match.
   c) Drogue deployment charge weight calculation

From the Ideal Gas Equation PV=NRT

Where: P = Pressure (Lbf / in^2)
V = Volume (in^3)
N = Mass of FFFFG black powder (Lbm)

Black Powder Constants* R = 266 in-Lbf / Lbm
T = 3307 °R (combustion temp)
(Noting 454 grams = 1 Lb)

For 12.5 Lbf / in^2, this equation reduces to

$N = 0.005D^2L$ (grams of FFFFG black powder)

Where: D = compartment diameter (in) = 7.5”
L = compartment length (in) = 5”

Therefore: $N_D = 0.005(7.5)^2(5)$
$\underline{N_D = 1.4}$ grams of FFFFG black powder

The total separating force (F_S) $F_S = PA$

Where: A = Bulkhead Area (in^2) = $(\pi/4)(D)^2$

$F_S = (12.5 \text{ psi})(\pi/4)(7.5)^2$
$\underline{F_S = 552 \text{ Lbf}}$

*Referenced from http://www.vernk.com/EjectionChargeSizing.htm
This separating force applies to both the drogue and main parachute compartments.

d) Main deployment charge calculation for 12.5 psi

$N_M = 0.005(7.5)^2(22)$
N_M = 6.2 grams of FFFFG black powder.

e) Both drogue and main charge weights were first estimated mathematically and then proven by ground testing. Following ground test verification, the charges to be used are as follows.

Drogue 1 1/3 grams FFFFG black powder
Main 6 grams FFFFG black powder

C) Recovery Initiation Device Testing and Verification

1) Both the primary and backup barometric control devices were ground tested by connecting small 12 VDC lamps to the drogue and main outputs of the respective controllers. A ¼" diameter clear plastic tube was then pressed against the pressure aperture on the barometric sensor and a vacuum was drawn by mouth. The lamps were then observed for the proper firing sequence.
2) Barometric controller wiring was checked prior to final assembly.

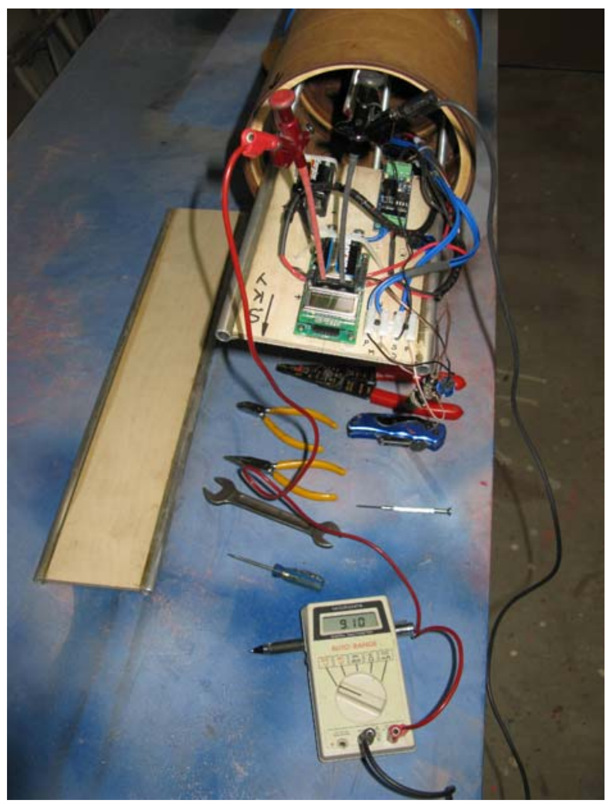


Figure 7: Barometric Controller Wiring Check

The main parachute deployment from the TAC-9C bag was ground tested to verify the size of the pilot parachute. This was accomplished by attaching the main parachute assembly to the rear of a pickup truck. The truck was then driven at a speed of 20 MPH (29.3 ft / sec).

The pilot parachute was released along side and to the rear the truck. At 20 MPH, a successful deployment was achieved. The drogue parachute is sized for a 60 Ft / Sec decent rate. This should allow enough speed to deploy the main parachute assembly.

Figure 8: Main Parachute Deployment Ground Test

V) Stability Evaluation

A) Launch Pad

The launch pad consists of an 8" long x 1 5/8" square Telistrut socket welded perpendicularly to a 3/8" thick steel base plate. The stabilizing legs are 10 Ft long - 1 5/8" square Unistrut rail. The stabilizing legs are attached to the base plate with ½' stud nuts fastened with wing nuts. The launch rail is a continuous, 145" long, 8020 Inc - 1515 rail extrusion. There are two 1 5/8" x 15/16" Unistrut channel diagonal braces for additional stability. The launch pad is also designed to tilt 20° from vertical to facilitate weather cocking on windy days.

Figure 9: Launch Pad

The launch rail can be lowered to a horizontal position and detached to facilitate easy mounting of the rocket. With the launch rail detached from the mounting rail, the launch rail is engaged with the rocket launch lugs while in a horizontal position.

The launch rail is then attached to the vertical mounting rail. Once fastened, the launch rail and rocket are rotated into the vertical position for launch.

Figure 10: Rocket Transport Wagon

B) Center of Pressure (CP) Calculations

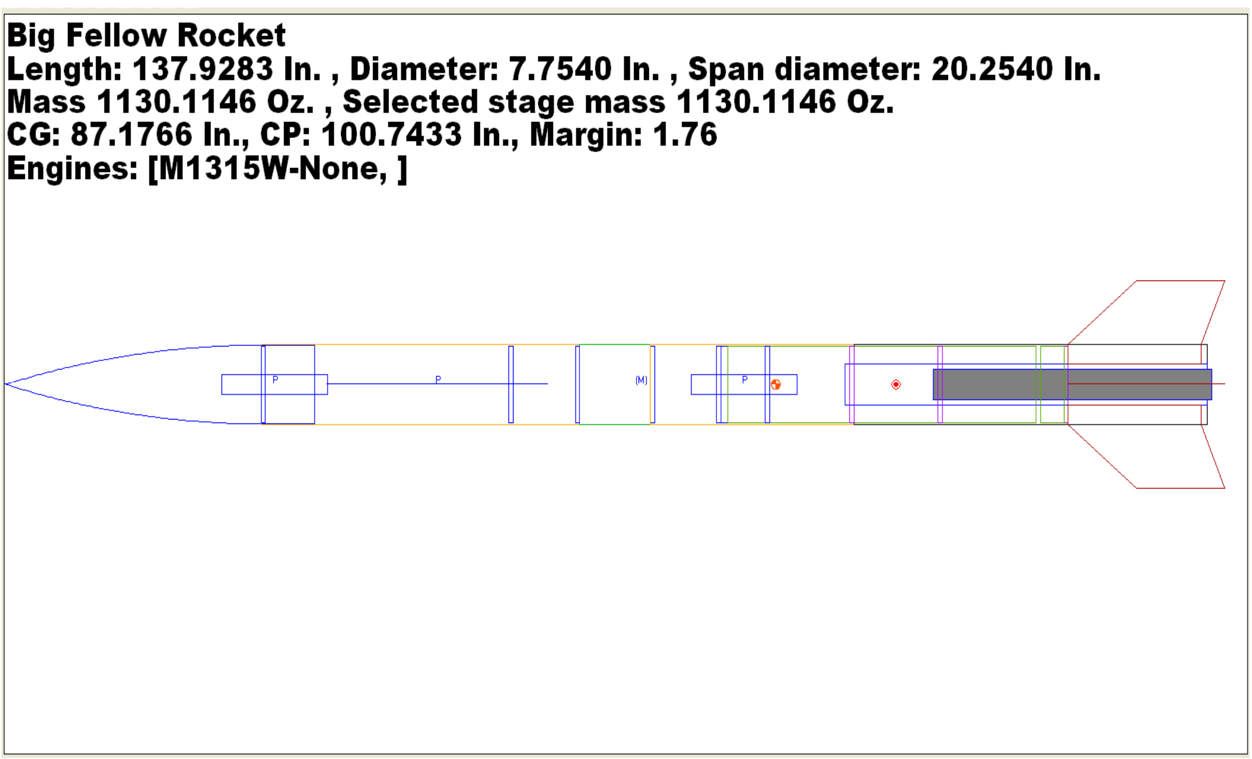


Figure 11: Center of Pressure with M1315W motor (RockSim 8)

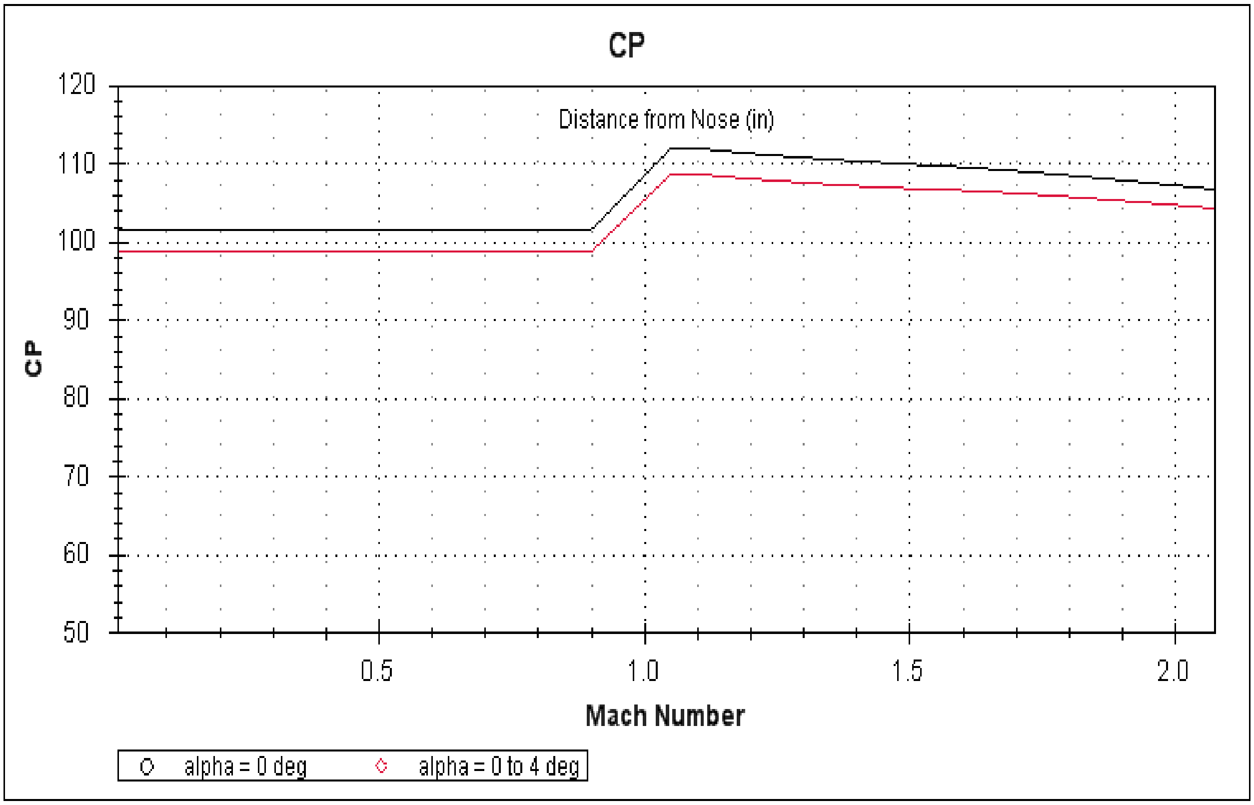


Figure 12: Center of Pressure w/M1315W vs Mach Number (RASAero 1.0.0.0)

C) Aft Center of Gravity Limit

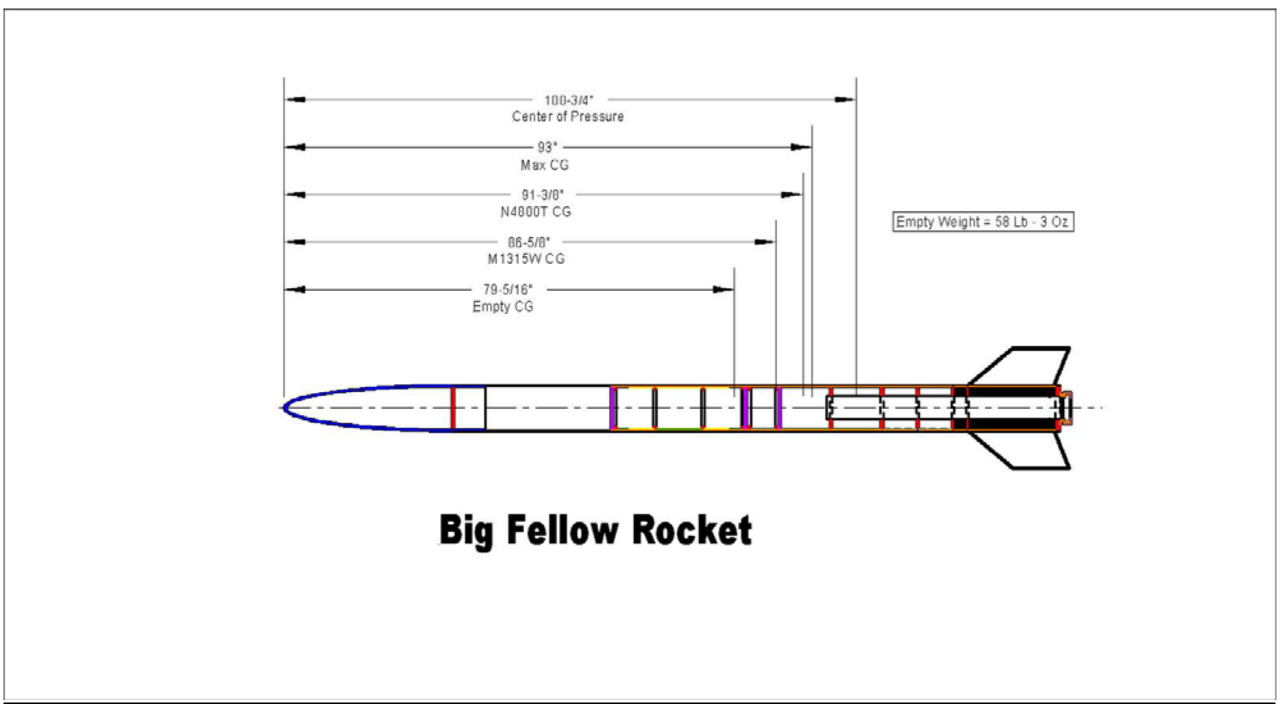


Figure 13: Aft CG Limit = 93" from nosecone tip

D) Drag Coefficient Chart

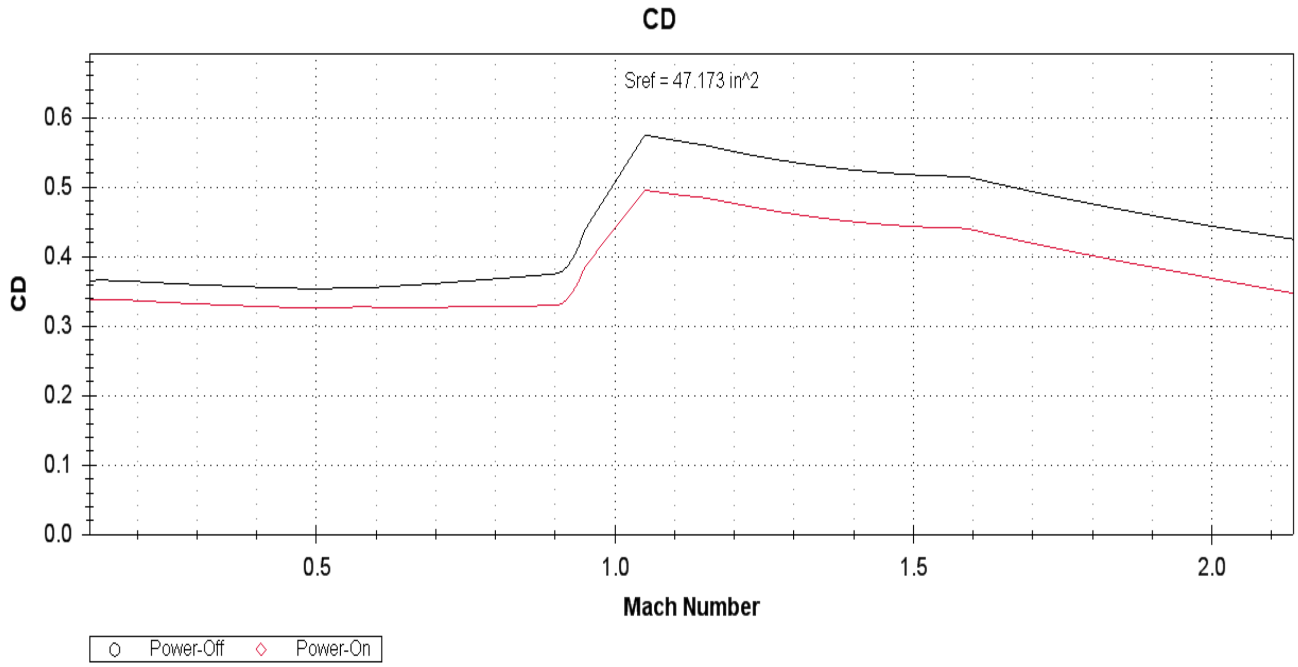


Figure 14: Estimated Drag Coefficient (C_d) (RASAero 1.0.0.0)

VI) Expected Performance Profiles at Varying Wind Speeds

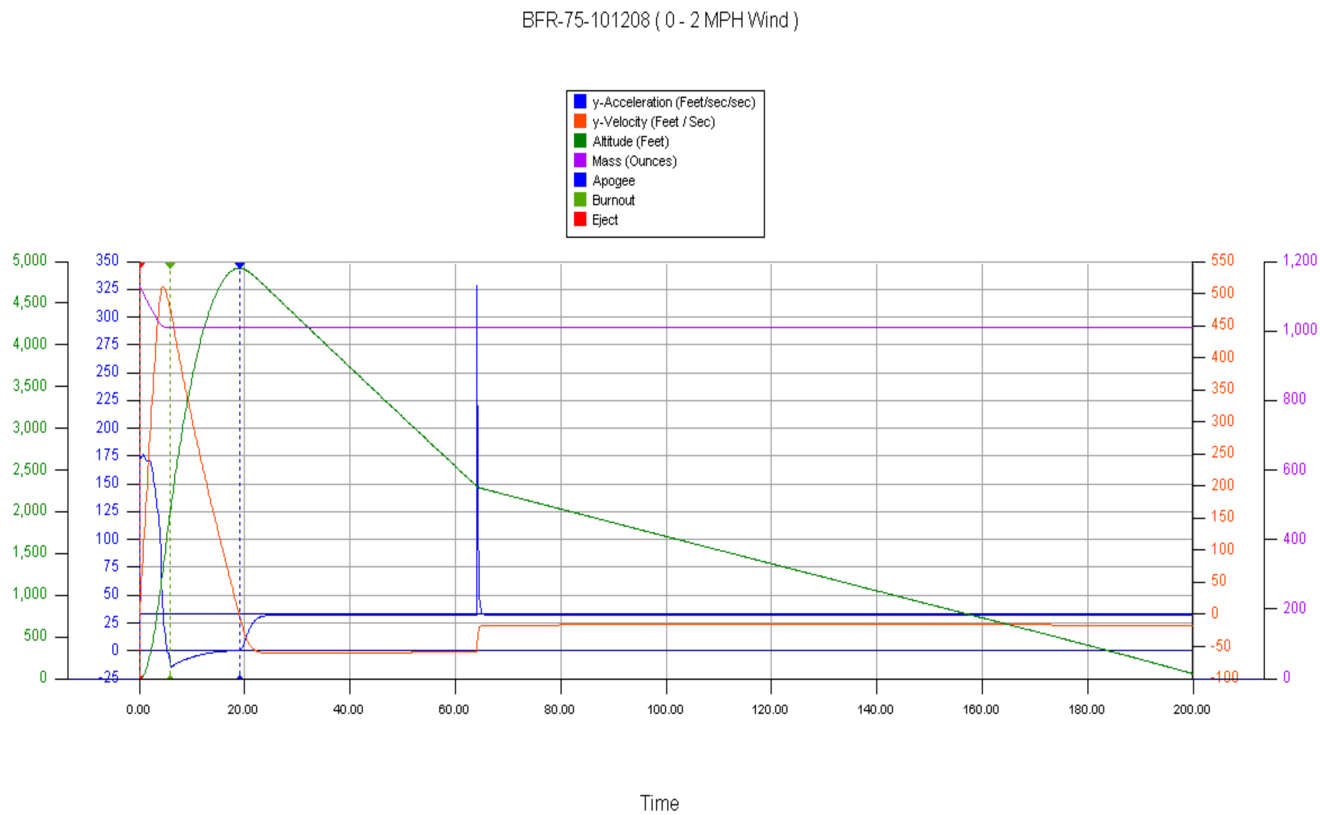


Figure 15: Expected Performance Profile with M1315W (0-2 MPH Wind)

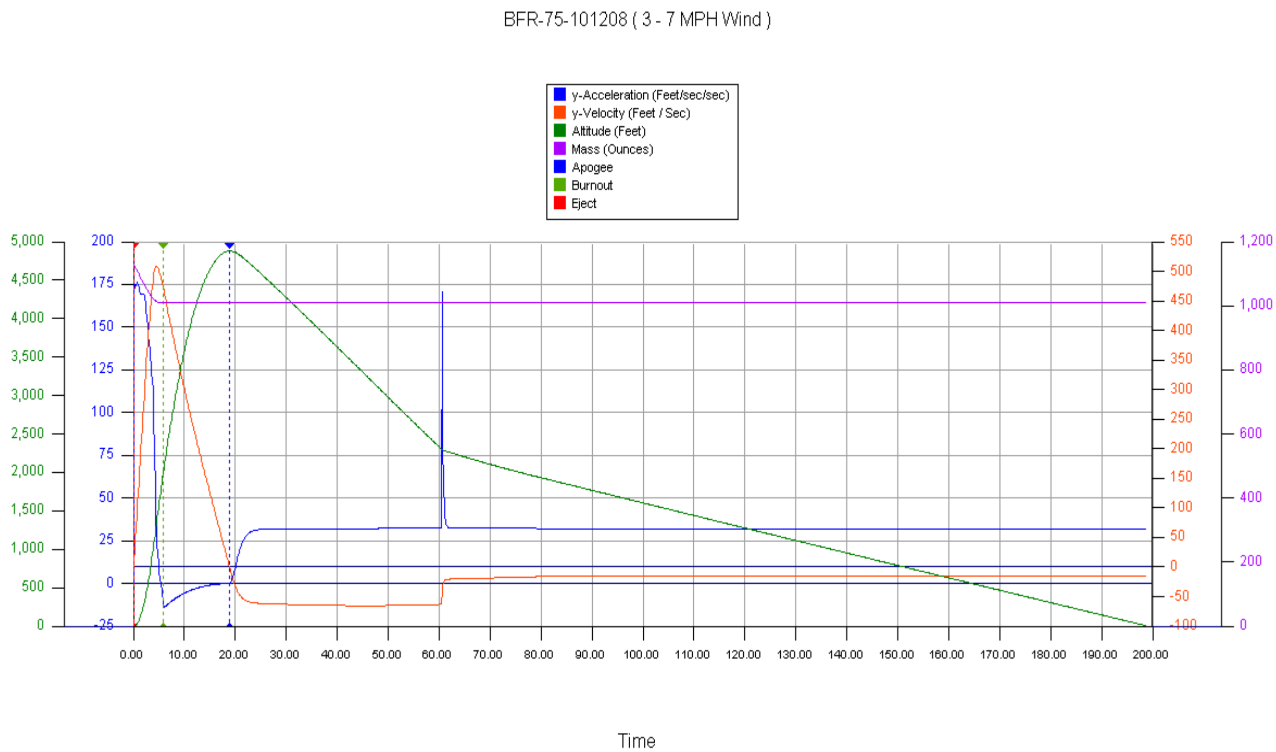


Figure 16: Expected Performance Profile with M1315W (3-7 MPH Wind)

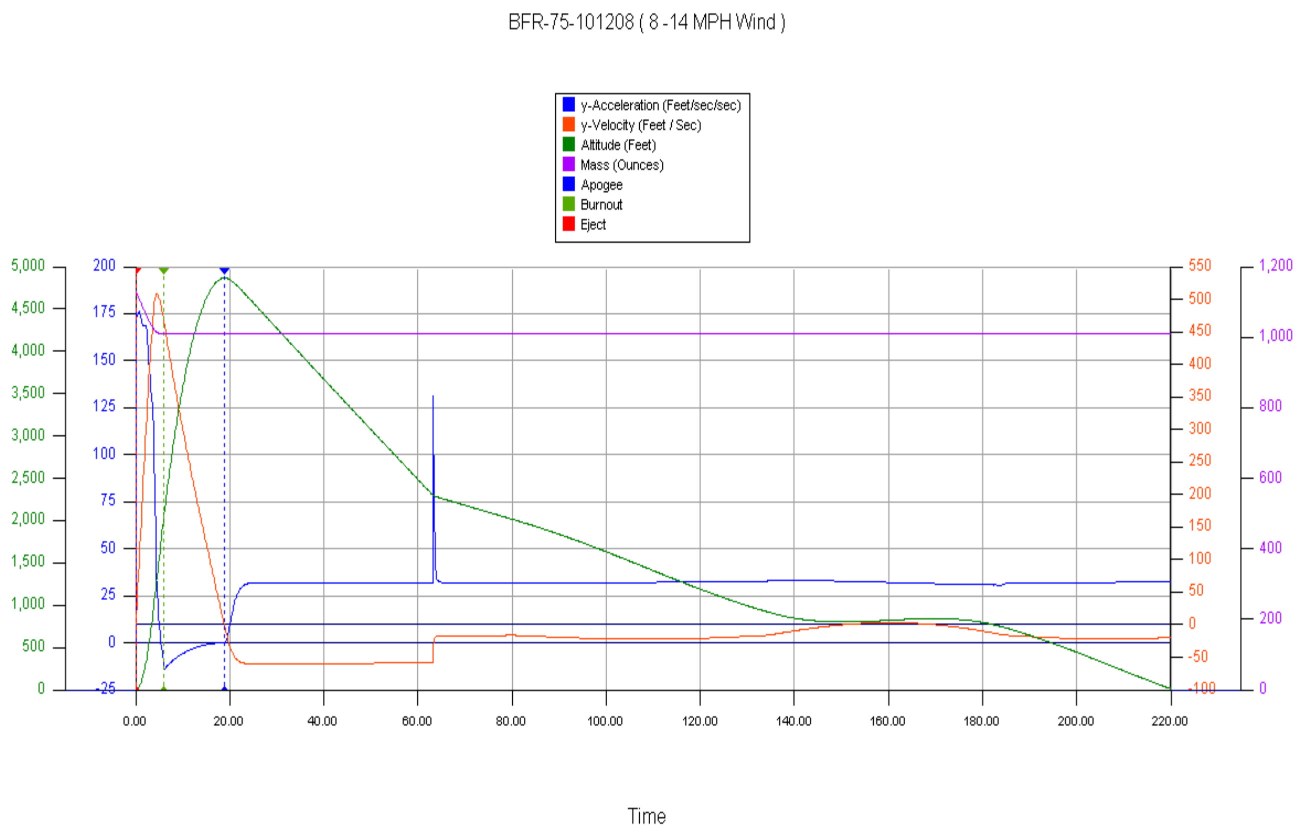


Figure 17: Expected Performance Profile with M1315W (8 - 14 MPH Wind)

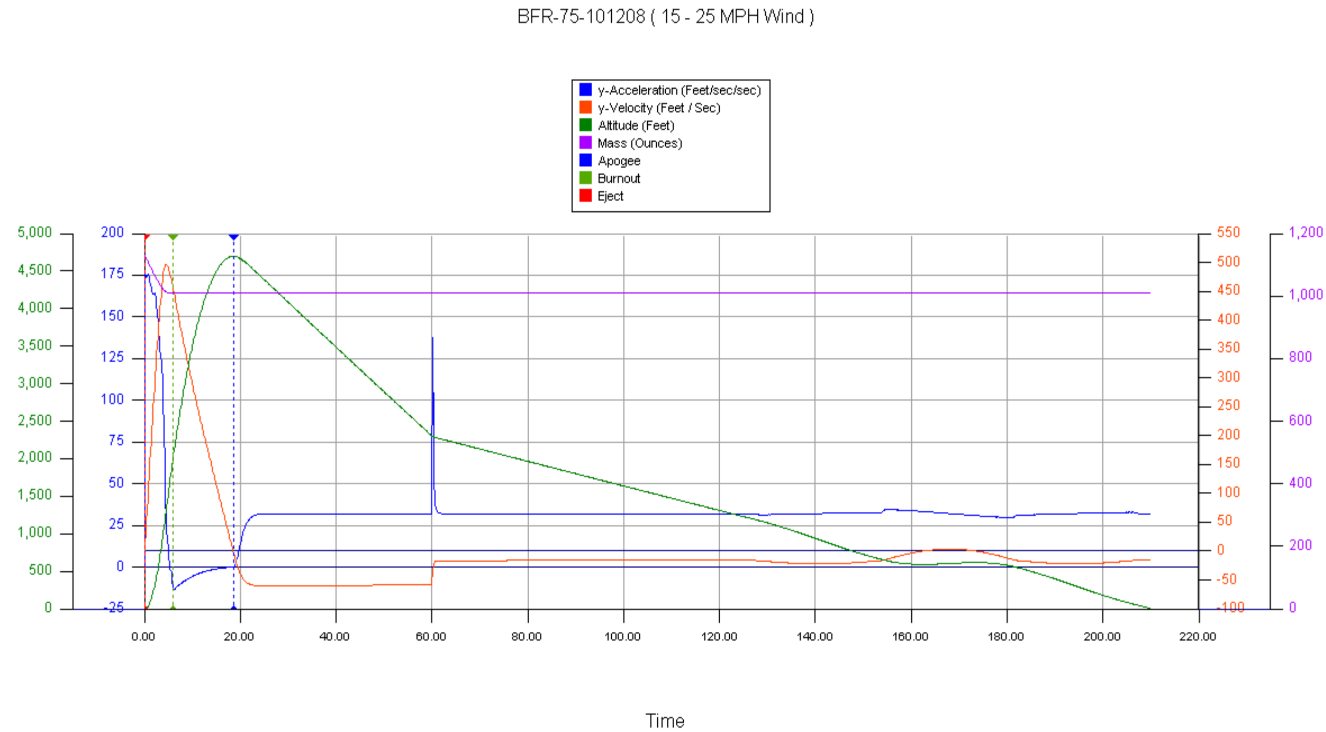


Figure 18: Expected Performance Profile with M1315W (15 - 25 MPH Wind)

VII) Additional Design Considerations

A) Launch Guide RockSim 8 Simulation Data

- Launch guide length: 120.0000 In.
- Velocity at launch guide departure: 53.1121 ft/s
- The launch guide was cleared at : 0.440 Seconds
- User specified minimum velocity for stable flight: 43.9994 ft/s
- Minimum velocity for stable flight reached at: 83.1274 In.

B) Fin Flutter

1) The dimensions of the fins on this rocket were chosen with the goal of designing for the highest velocity possible. Although the initial flight will be on an Aerotech M1315W (75/6400), this rocket was designed for long 98mm diameter motors. After an initial, all component assembly to verify the RockSim 8 CG location, the fin design was re-evaluated. The initial fin design was cut down to yield a higher fin flutter velocity. The phenomenon of “Fin Flutter” is examined in NACA-TN-4197. There is also a useful Excel based calculator accessible online at http://www.info-central.org/index.cgi?design. A swept configuration was chosen as the best general fin shape for this design. The shear modulus of 3/16” thick G-10 sheeting was also investigated. After speaking with several manufacturing sources, the G-10 shear modulus in the abovementioned calculator was raised from 1 X 10^6 psi to 1.57 x 10^6 psi. Using the swept

fin row portion of the abovementioned calculator, a flutter velocity of over 810 MPH (1190 Ft/Sec) was attained after numerous refinements. After the design was finalized, the initial fin configuration was cut down to size with a wet tile saw using a brass bonded diamond blade. The leading and trailing edges of the fins were then given a 10° chamfer. The outer fin chord was left square to the main fin surfaces.

References:

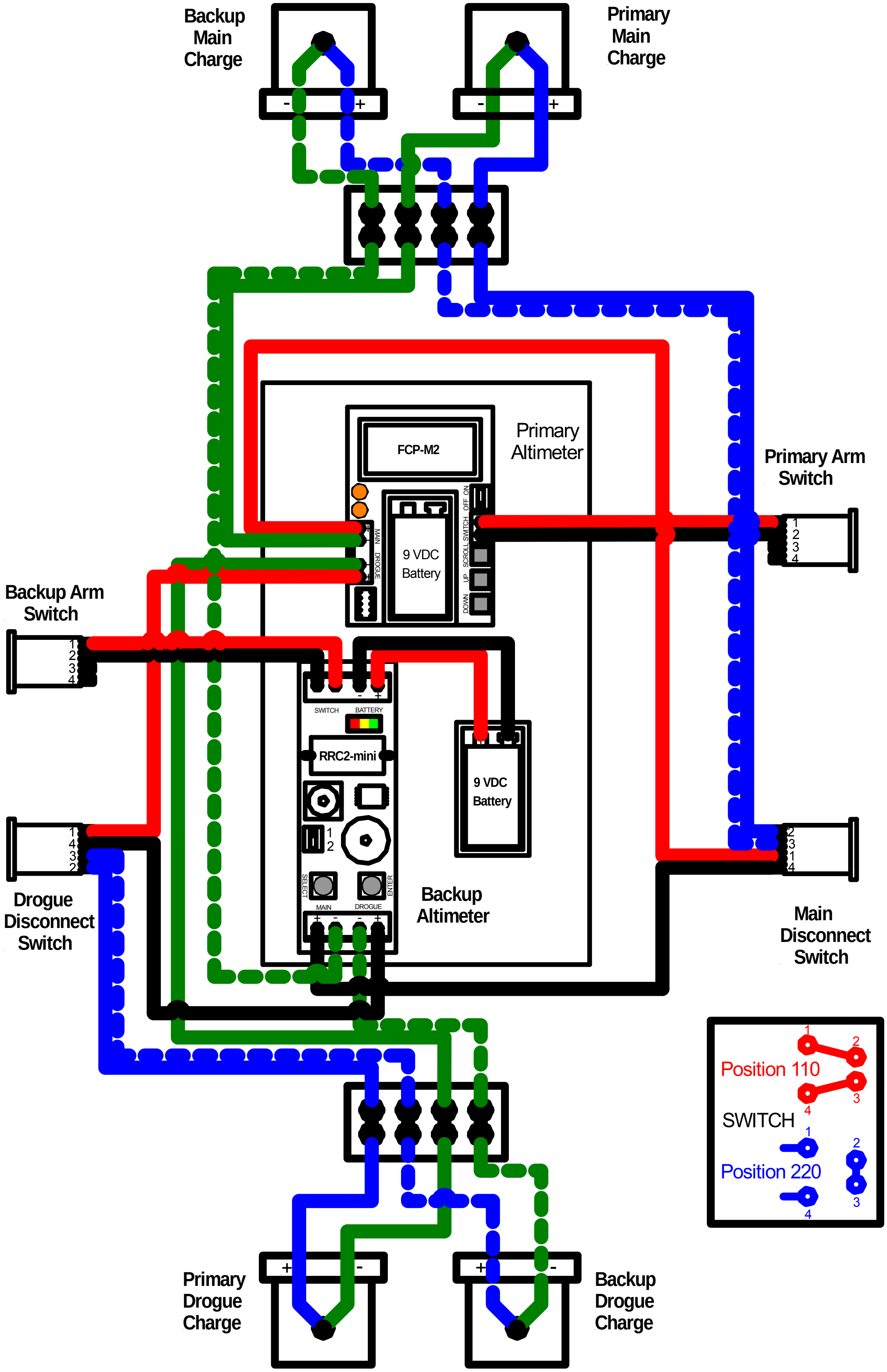
1) Design Simulation Programs

   a) RockSim 8
   b) RasAero 1.0.0.0

2) Other Design References

   a) Barrowman Equations http://my.execpc.com/~culp/rockets/Barrowman.html
   b) NACA-TN-4197 (Fin Flutter Equations)
   c) Info-Central.org (Fin Flutter Calculator)
      Giant Leap Rocketry http://giantleaprocketry.com/hpdefault.asp
   d) Public Missiles http://www.publicmissiles.com/
   e) Vernk.com (Ejection Charge Sizing)
   f) Handbook of Model Rocketry G Harry Stine, 7 Th Edition
   g) NASA http://exploration.grc.nasa.gov/education/rocket/shortr.html
   h) Modern High-Power Rocketry 2 Mark Canepa
   i) Parachute Decent Rate Calculator ver 3.3 by Jordan Hiller http://www.onlinetesting.net/cgi-bin/descent3.3.cgi
   j) Rocketry On-Line Forum http://www.rocketryonline.com/

Appendix A



Backup Main Charge
Primary Main Charge
Primary Altimeter
FCP-M2
9 VDC Battery
Primary Arm Switch
Backup Arm Switch
RRC2-mini
9 VDC Battery
Backup Altimeter
Drogue Disconnect Switch
Main Disconnect Switch
Position 110
SWITCH
Position 220
Primary Drogue Charge
Backup Drogue Charge