**The APEX Rocket**
American Paratrooper Ejection X-periment


Launched on October 12, 2011

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# Mission

The objective of the American Paratrooper Ejection X-periment (APEX) rocket is to be a means to transport military personnel and supplies over long distances in a short amount of time. The transport must be reliable, disposable, and reasonably cost effective. APEX is designed by a private engineering firm contracted by the United States military. This firm specializes in aerospace defense, including missiles and troop transport.

The global community has become complex and conflicts between countries have become a prime concern for the United States, which is a major entity in the world. With the increasing energy demands of nations, and limited energy resources in the world, many regions are volatile and this result in military conflicts. The United States wishes to play an active role involving itself in these conflicts in order to protect its personal interests, including accessing resources, promoting democracy, and other related goals. In order to effectively manage these conflicts, the Department of Defense desires a means to quickly deploy military units to a foreign country should they be required. The ability to respond quickly to threats is a great military advantage and would allow the United States to further assert its military superiority in the world.

While the United States has many military outposts around the world (i.e. in Germany, Japan, etc...), the costs involved in maintaining these outposts have become unsustainable. Military bases in regions that are not volatile, such as Germany, still cost the United States billions of dollars per year. If the U.S. Military was able to transport troops across the globe quickly, the need for bases would be reduced. Billions of dollars could be saved by consolidating military forces inside U.S. borders. Constructing a reliable rocket transport for a reasonable cost could provide the same military utility while saving money, should the transports be necessary.

The APEX rocket consists of two payload bays. The far forward section, close to and including the nose, contains military supplies including vehicles and armament. Behind this, military personnel are secured so that they can exit first. This safety feature allows the crew to escape safely and leave the vehicles behind, if necessary. Once the rocket reaches its destination, it undergoes two stage separation. The first stage splits the rocket so it will fall rapidly above the target destination. At a lower altitude, the military troop capsule is ejected and troops parachute down alongside the rocket to the desired landing spot. Releasing them at the second stage of separation allows for a more precise landing, since there is less drift time. Allowing the troops to leave the rocket on their descent also allows the unit to be less susceptible to the enemy, which may intercept and destroy the rocket on its descent, eliminating the entire military unit. By ejecting the troops away from the rocket, it is more difficult for hostile forces to eliminate the entire unit. Once the rocket lands on the ground, the soldiers reenter and open the supply bay, driving the tanks, humvees and armaments out.

# Design

The overall rocket is 5.60 lbs. and 62 in. long, composed of the components below.

**Table 1.** List of main components and their properties.

| Component | Length (in.) | Weight (g) |
|---|---|---|
| Nosecone | 9.5 | 115.2 |
| Extra mass (beads) | 0 (inside nose cone) | 1590 |
| Top Shock Cord | 48, 3 (wrapped up) | 16.5 |
| 48” Parachute | 8.5 (wrapped up) | 95 |
| Payload | 11.625 | 18.9 |
| Piston+Ematch+Denim | 2.5 | 28.3 |
| Piston Shock Cord | 72, 3 (wrapped up) | 63 |
| Avionics Bay | 11.5 | 425 |
| Ematch+Denim | 2.5 | 7.5 |
| Bottom Shock Cord | 96, 3.5 (wrapped up) | 33 |
| H186RT Engine | 15.4 | 472.0 |
| Fins | 6 | 5 |
| Motor Mount | 10 | 240.1 |

**Table 2.** Material specifications and dimensions

| Property | Value |
|---|---|
| Body Tube Outer Diameter | 2.26 in. |
| Body Tube Thickness | 0.125 in. |
| Coupler Outer Diameter | 2.174 in. |
| Coupler Thickness | 0.125 in. |
| Motor Mount Diameter | 1.496 in. |

# Avionics Bay

The avionics bay attaches the top and bottom halves of the rocket together, provides two camera views, an altimeter, and the charges to initiate separation and parachute deployment. Aboard the bay are two Linoo Fly DV cameras, one recording horizon with the other recording ground, a PerfectFlite StratoLogger SL100 altimeter, a 9V altimeter battery, the frame, and wiring for the ematch charges. The design parameters of the bay are provided below, with a schematic of where components are mounted.

**Table 3.** Avionics bay component specifications

| Parameter | Value | Units |
|---|---|---|
| Bay Length w/ Coupler | 11.5 | Inches |
| Body Tube Outer Diameter | 2.260 | Inches |
| Body Tube Thickness | 0.125 | Inches |
| Coupler Outer Diameter | 2.174 | Inches |
| Coupler Thickness | 0.6 | Inches |
| Acrylic Plate Width | 0.8 | Inches |
| Acrylic Plate Length | 7.825 | Inches |
| Camera Window Area | 1.0 | $Inches^2$ |
| Device Access Diameter | 0.5 | Inches |
| Mirror Area | 1.0 | $Inches^2$ |
| PVC Length | 8.0 | Inches |
| Camera Allowance | 0.25 | Inches |
| Battery Allowance | 0.875 | Inches |
| Weight of Bay | 0.91 | Pounds |

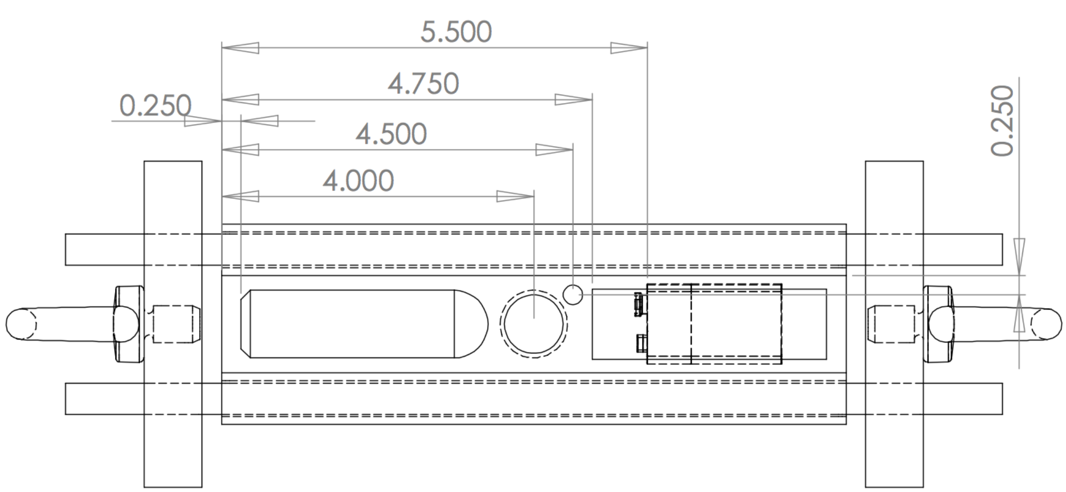


**Figure 1.** Avionics bay schematic showing non-symmetric component placement.

# Separation & Recovery

The separation and recovery design for this rocket is a two-stage separation with the first stage occurring at apogee (roughly 1250ft) and the second at 300ft. The first stage of separation separates the bottom section of the avionics bay from the rear section of the fuselage resulting in two separate rocket components connected by the bottom shock cord. This separation increases the drag on the rocket resulting in a slightly slower decent rate. At 300ft the second stage of separation occurs at which the separation charge forces the piston up through the top section of the fuselage, pushes off the nosecone and ejects the parachute and the payload. Once ejected, the parachute will open and greatly reduce the decent rate of the rocket.

The main components of the separation & recovery system of the rocket include the three shock cords(top, piston, bottom), the parachute, the payload, the separation charge, the piston, and insulation for the piston. Dimensions for these are provided in Table 1.

# Fins

The fins are made of ⅛" plywood. The thickness of the material limits the design. Further the grains in the wood must be in the span-wise direction such that if it shears, it does not reduce the chord. The root and tip chord are the same measuring 4". This design must be very stable to satisfy its purpose of transporting troops and supplies.This goal is accomplished with a large center of pressure at a distance from the center of gravity. In order to have a strong center of pressure the span should be as long and as far behind the trailing edge of the rocket as possible. Since this design is generic, a simple 45º sweep was chosen. The design team felt that a span any longer than 8" would be unproductive. The final design features a 3"x .315" protrusion that is inserted into the body tube and epoxied to the motor mount in accordance with the previously designed fin mounting system.

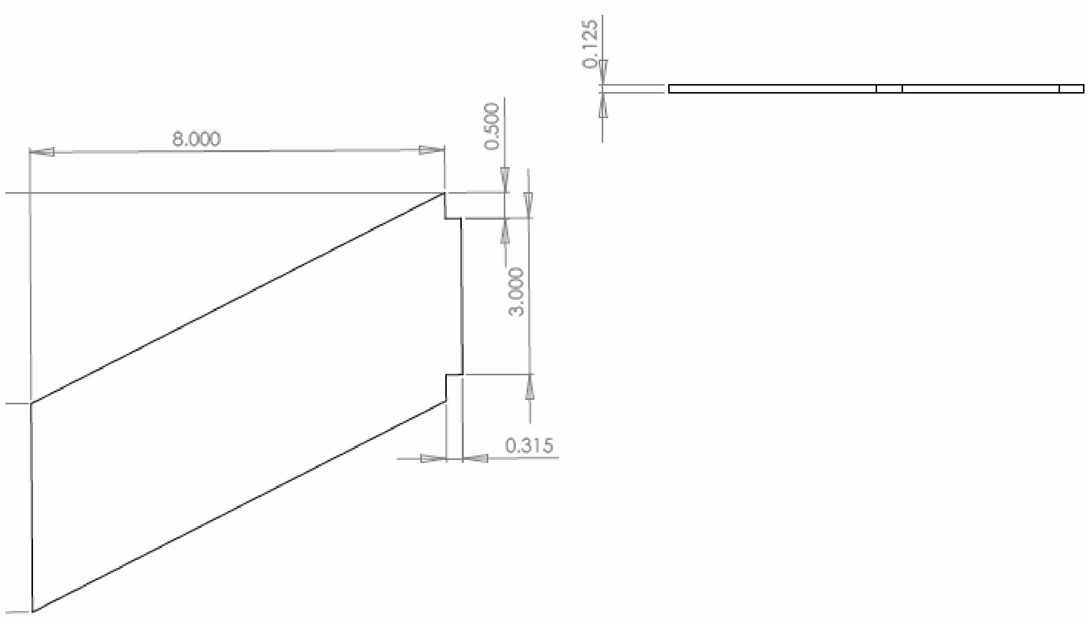


**Figure 2.** Fin Dimension

# Launch Pad

The launch pad consists mostly of 80/20 aluminum extrusion. This design was selected due to its practicality, portability, and ease of construction. The aluminum extrusion was used to construct the base of the pad, the eight foot launch rail and the legs. An aluminum plate measuring 1' x 1' was then attached to the base using a hinge in order to provide angling of the launch rail depending on the ambient conditions. The design is made to be portable as well. The legs are mounted so that they fold up flush against the square base. Removing the launch rail allowed for the launch pad to collapse into a 1' x 1' x 2" box.

**Figure 3.** Launch pad set-up prior to having the rocket mounted.

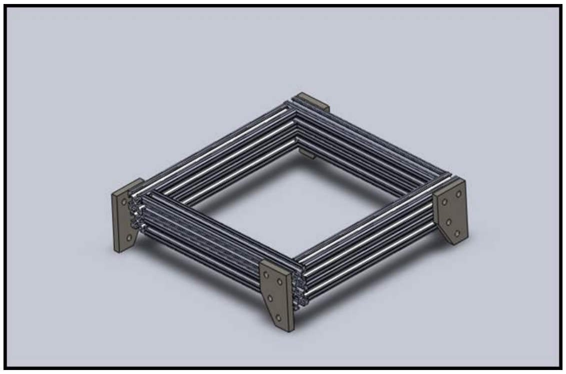

**Figure 4.** Launched pad folded into portable position.

# Motor Mount

The purpose of the motor mount is to secure the motor into the center of the aft of the rocket. The motor mount is 10 inches long and fits into the aft of the rocket. The motor casing is fixed into the inside of a 38 mm (1.5 in) flexible phenolic tube. This phenolic tube is then centered into the aft of the rocket by using two centering rings that are attached to the inner surface of the body tube of the rocket by using a 30 minute epoxy. Three screws, three nuts, and an aluminum retention ring, are used to secure the motor into the motor mount. The drawing below illustrates the different parts that were used in order to fulfill the requirements necessary to successfully launch the rocket, and the table displays the specifications of the motor mount.

**Table 4.** Motor Mount Properties

| Motor Mount Part | Value |
|---|---|
| Wood Centering Ring Diameter | 1.5 in |
| Wood Centering Ring Thickness | 0.125 in |
| Phlexible Phenolic Tube Diameter | 1.5 in |
| Phlexible Phenolic Tube Length | 10 in |
| 4-40 Machine Screws | 1 in |
| Aluminum 6101 Plate Thickness | 0.125 in |
| Aluminum 6101 Plate Diameter | 2.5 in |

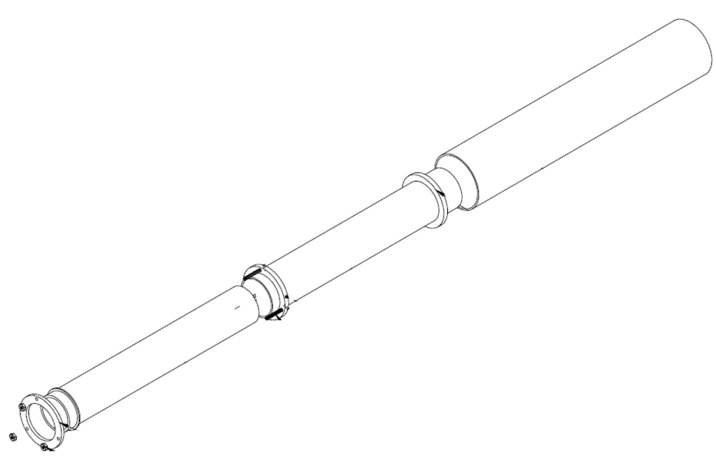

**Figure 5.** Motor retention exploded view

# Construction, Assembly & Pre-Flight

## Avionics Bay

To build the avionics bay, a clear plexiglass sheet was cut to size to act as the mounting plate, threaded metal rods were cut to length, and PVC tubing was cut as a sheath for the rods. The plexiglass piece was attached to the rod sheaths with clear packaging tape, then holes were drilled to mount each component, and allow the battery wire to pass. Wooden coupler rounds were glued together to contain the bay and were held in place with nuts on either side of the mounting plate, and each bulkhead. The altimeter and button were screwed in place, the cameras were positioned, then affixed with hot glue. Lastly, the battery was attached with double-sided tape.

The outside tube was cut to length, along with two 2 inch couplers. Holes were drilled for camera lenses, camera access, and pressure equalization. A periscope was modeled off of the Mark I design and mounted outside one camera hole. A square opening was created for the second camera to mount a lens with clear tape on the exterior. The lens was fashioned from the clear plexiglass by bending it over extra coupler material, using a heat gun to shape it. Components were wired together, axial mounting holes were drilled in each coupler, and the bay was assembled as pictured below.

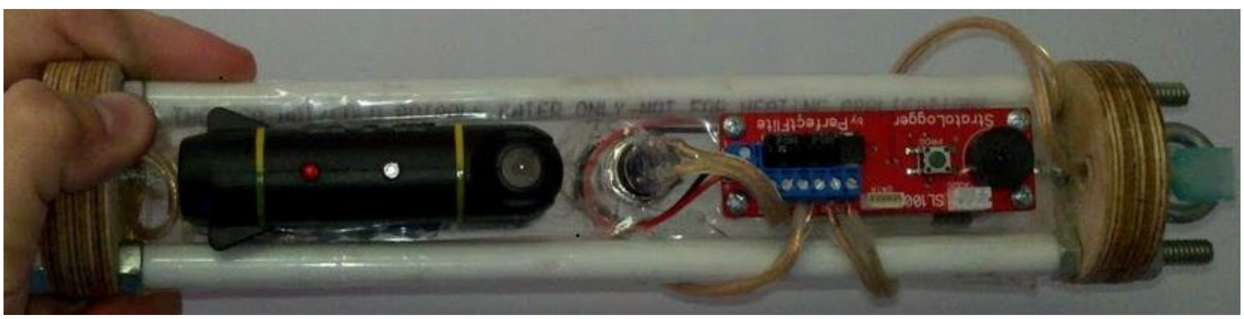

**Figure 6.** Top view of avionics bay showing ground-view camera and altimeter.

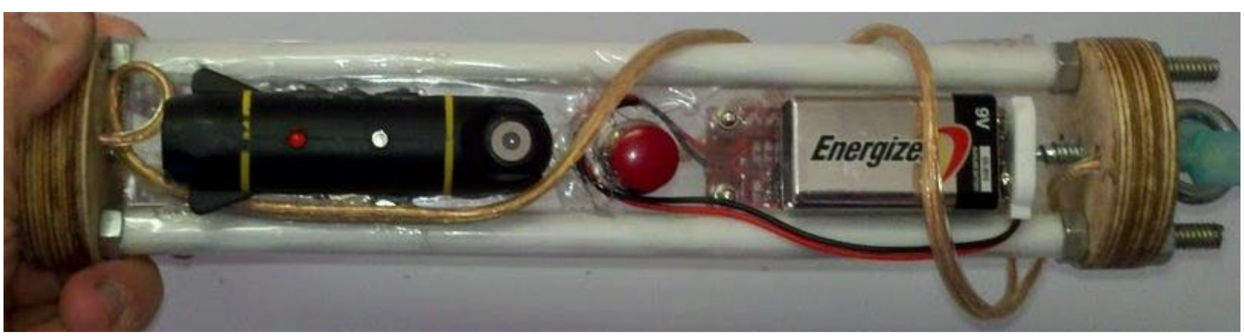


**Figure 7.** Bottom view of avionics bay showing horizon camera, power button and battery.

**Figure 8.** Exterior of avionics bay with periscope (top), window (bottom) and access holes.

Finally, the altimeter was programed to separate 0-seconds after apogee and deploy the parachute at 300 ft. Pre-flight, the power button was pressed, cameras turned on, and 'OK' was pressed on each camera to initiate recording.

# Separation & Recovery

In order for separation to occur, separation charges need to be made. These charges are wired to the avionics bay and programmed to go off at a certain altitude. To construct a separation charge place two ematches in the center of a 12"x5" piece of aluminum foil and tape them down. Next, fold the aluminum foil to make a flap around the ematches, add the desired amount of black powder on the tips of the ematches, fold the remaining aluminum foil to create a cylinder, and wrap aluminum tape around the cylinder to ensure a compact and leak free charge. In order for the avionics bay to be protected from the separation charge, insulation is needed. The insulation used was denim because it is both inexpensive and flame resistant.

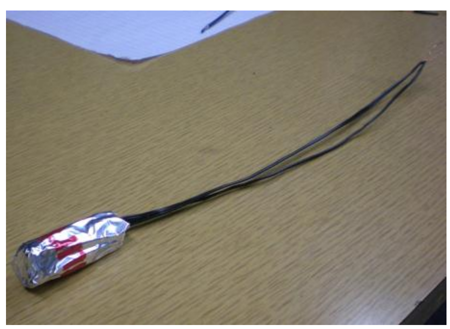

**Figure 9.** Separation Charge (Ematch)

In order for the parachute and payload to be ejected and the nose cone to be pushed off a piston is needed. The piston kit used contains a cylinder, having about the same diameter as the rocket's inside diameter, a bulk plate, a D-ring, and a 6ft section of ⅝" shock cord. To construct the piston, the shock cord is pulled through the bulk plate, then pulled through the D-ring, and then pulled back through the bulk plate where it is tied and epoxied to the bulk plate's bottom. The bulk plate is then attached to the top part of the cylinder and epoxied. The piston is then sanded down so that it has the ability to glide through the inside of the fuselage, but still creates a uniform fit within the fuselage. The separation charge is placed inside the piston, so that when the charge is ignited, the pressure difference created inside the fuselage causes the piston to shoot up through the fuselage, ejecting the necessary components.


**Figure 10.** Piston with shock cord attached

To attach all the rocket components together, shock cords are used. Total shock cord length used in the rocket should be approximately three times the length of the rocket. In this design, we used 18ft of shock cord with 4ftx3/8" that connects the nose cone to the piston(top), 6ftx5/8" that connects the piston to the avionics bay (piston), and 8ftx3/8" that connects the avionics bay to the motor casing (bottom). To secure the shock cord to the I-bolts throughout the rocket, a grapple hitch knot is used.

In choosing the parachute size, several factors were taken into account which include: desired decent rent (20-30ft/s), final weight of the rocket, and available space within the top fuselage. For this rocket design, a 48" X-type parachute was selected. The diagram below shows the proper folding technique of the parachute, so that it opens properly when ejected.

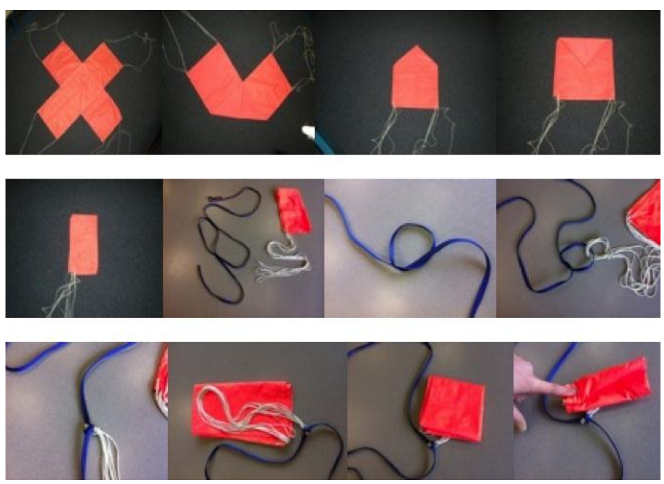

**Figure 11.** Parachute Folding Technique

The payload used in this rocket was army men figurines (9) which represent real life military personnel. Ideally, these men when ejected in an open capsule that is located in front of the parachute and they would parachute to the desired target. However, for safety reasons the men were tied to the top shock cord and brought down with the rocket.

The figure below shows the approximate location of each component of the separation recovery design. Note: the payload is attached on the shock cord in front of the parachute and behind the nosecone.

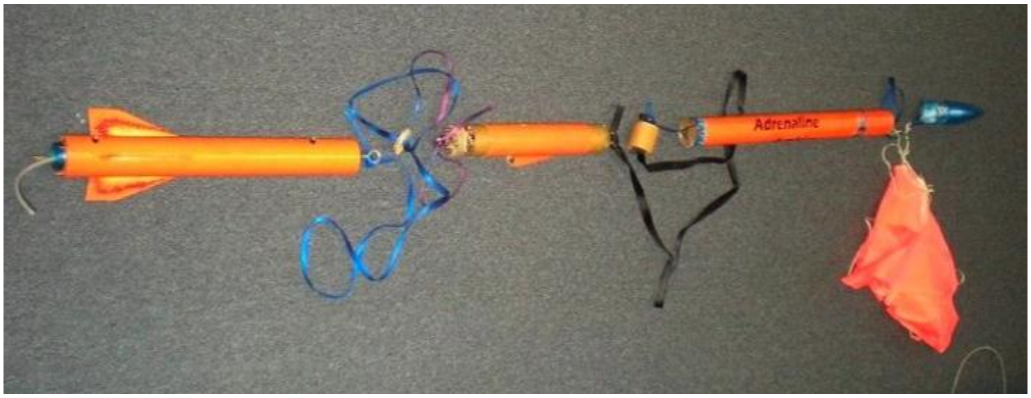


**Figure 12.** Assembly of Separation & Recovery Components

# Fins

The fins were first carefully measured and marked on the plywood in accordance with the design. Each fin was cut in a band-saw along the designated lines. Following is the instruction for how the fins were mounted. This system utilizes holes in the body tube that are press fit.

*Step 1*: Drawing the slots

In order to cut the fin slots it is necessary to first outline the cuts in pencil. As stated above this design features three fins, and the body tube is 56mm in diameter. A fin guide paper matching this design criteria is printed from payload bay rocketry and cut out. The guide paper was then wrapped around and secured on the outer surface of the body tube. Marks were made on the body tube matching each line along the fin guide paper. The guide paper was then removed from

around the body tube and the body tube was put into the fin mounting device. The small marks made using the guide paper, were extended along the length of the tube using the aluminum plate as a straight edge (see fig. X). Circles are drawn around the tube, by simply turning the tube and keeping the pencil still, to mark the top and bottom of the 3” slots. This allows each slot to be drawn in the same location along the longitudinal axis of the body tube. Finally the thickness of a fin (.125”) is marked along the body tube.

**Figure 13.** Slot drawing/cutting rig

*Step 2*: Cutting the Slots

The portions of the body tube where the rings intersect with the longitudinal lines indicate the sections that needed to be cut to form the fin mounting slots. The previously drawn sections were cut from the body tube with a sharp X-Acto knife. As with the pencil, the blade of the knife is kept flat against the top edge of the aluminum plate. Each cut is made on the inner side of the line to ensure a snug fit for the fin.

*Step 3*: Epoxy

Epoxy was applied to the bottom of the fin insert. Each fin was put in through the slots and pressed down firmly onto the motor tube.

# Launch Pad

The majority of the launch pad was constructed using 80/20 aluminum extrusion. Two eight foot pieces were ordered for the assembly, one for the launch rail and the other was used to manufacture each of the eleven inch legs. The legs were cut to be this short so that they would fold and tuck neatly underneath the aluminum blast plate. Each piece of 80/20 was attached together using using a single, two-hole, 90 degree bracket fastened to the 80/20 using quarter inch fasteners and t-nuts tightened by an allen wrench.

**Figure 14.** The 90 degree angle brackets used to connect the legs and base.

The blast plate  required a little more manufacturing.  Four holes had to be drilled to allow the hinge to be screwed on.  An additional three holes were made at the center plate of the plate for the mounting of the launch rail.  The last two holes milled we for the ignition fuse and a safety strap for preventing the launch pad from angling too much.

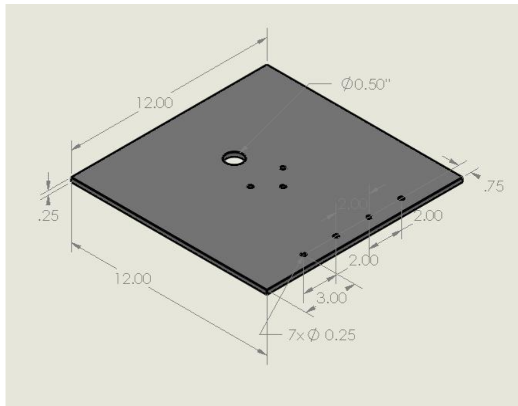


**Figure 15.**  Dimensioning of the blast plate.

# Motor Mount

The construction process is divided into four steps to break down the manufacturing and attachment of the 38 mm tube inside the rocket's body tube where the motor is secured.

*Step 1*: Mount screws into centering ring
· Place (3) 4-40 1 inch machine screws midway into the wood centering ring with holes, and apply epoxy to centering ring surface where head of screw will rest and to the top half of screw threads.

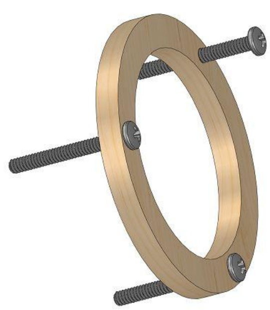

**Figure 16.** Machine screws being epoxied entering ring with holes

*Step 2*: Secure centering rings onto the 38 mm tube
· Use epoxy to secure the plain centering ring 1 inch from nose end of 38 mm tube
· Use epoxy to secure the centering ring w/ screws facing towards nozzle end, 3/8" from nozzle end of 38 mm tube.

**Figure 17.** Mounting of the centering rings onto the 38 mm tube using epoxy

*Step 3*: Fix the sub-assembly from step 2 into the rocket's body tube
· Apply a layer of epoxy up to 9" inside the 54 mm rocket tube using the long epoxy application stick, insert 38 mm tube into rocket. Refortify with extra epoxy on the rear centering ring.

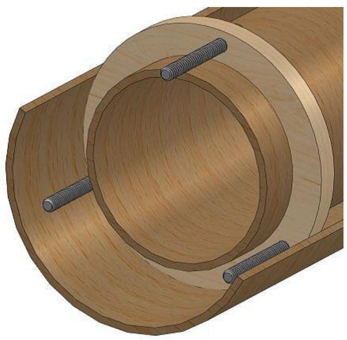

**Figure 18.** Epoxy the sub-assembly into the rocket's body tube

*Step 4*: Insert and secure the rocket motor into the 38 mm tube
· Slide the motor casing inside the 38 mm tube, cover with the aluminum retention ring, and secure with (3) 4-40 Machine Screw Nuts.

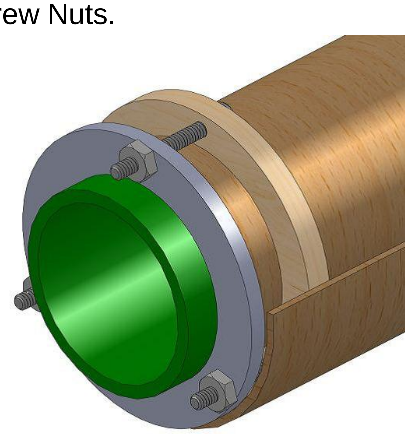

**Figure 19.** Secure the motor casing into the 38 mm tube using the 4-40 machine screws/nuts over the aluminum retention ring

The following pictures are the final product that was used for launching the rocket.

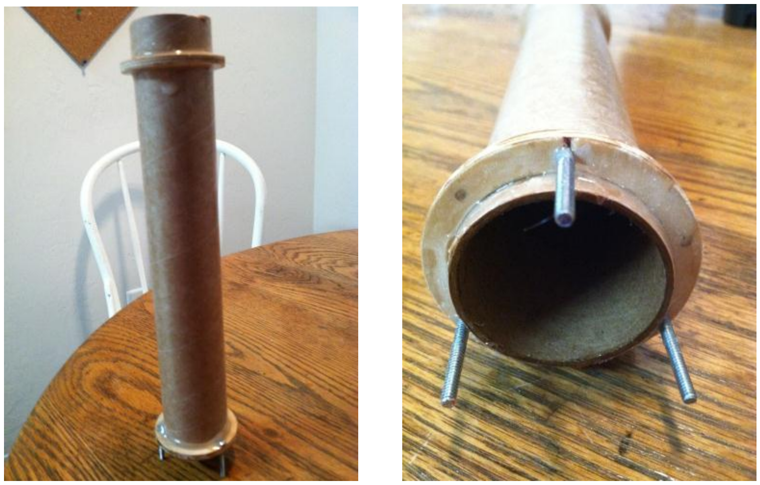

**Figure 20.** Completely assembled motor mount

# Final Assembly

The body tube was cut using a band-saw to the necessary dimensions; 26.5” for top section and 17” for the bottom section that holds the motor and fins. Both the fins and body tube sections were painted silver with spray paint. The motor mount was installed before the fins attached using liberal amounts of epoxy on the protrusion and fillets. Before the epoxy was completely dry, the lower body tube was painted to illicit a “welded” appearance. On launch day the shock chords were attached through the rocket, and the necessary amount of weighted beads were secured in the nose cone. When the wiring and programming of the avionics bay was completed, the assembly resembled figure 12. Each part was connected, and lastly the launch rail buttons were installed. It should be noted that the final weight caused the fins to buckle if unsupported, as they extended past the bottom of the rocket.

# Performance

On flight day the temperature was approximately 83°F and 80% humidity. Once launched, the rocket rose to an apogee of 1,034 ft. as shown in the figure below. It is clear where shear forces tore off the first fin at 4.5 seconds, and the second fin at 5 seconds. The gradual decline after apogee (marked as D) is due to the parachute deploying there instead of at 300 ft (marked as M).

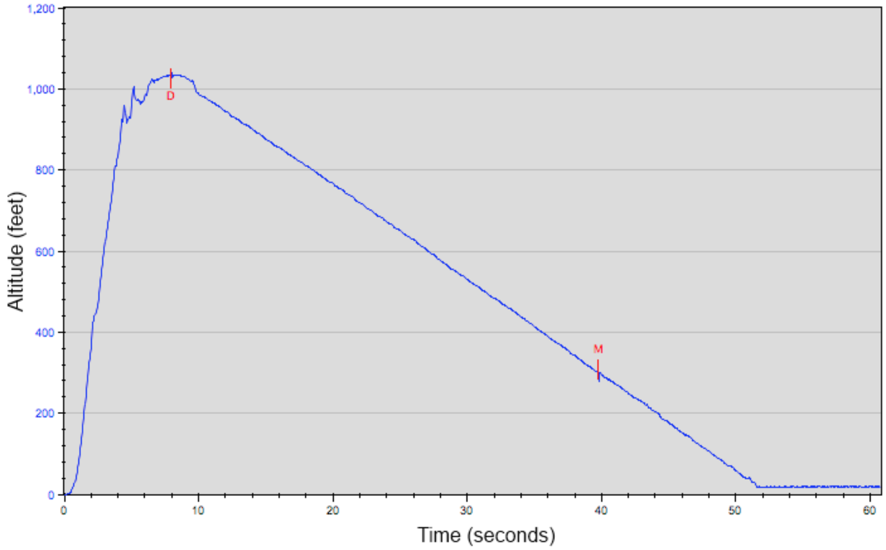


**Figure 21.** Actual flight altitude path for the APEX rocket.

Rocksim predicted an apogee at 1,458 feet, a far cry from the 1,034 feet reached. The discrepancy of 424 feet, 29% of the predicted altitude, is likely due to two main factors. Firstly, the fins shearing off removes all stability from the rocket and forces it to move violently, instead of gracefully, through the air. Secondly, the engines used on launch day were malfunctioning, and the rocket likely did not get its rated amount of thrust. Other factors include the periscope for ground-view camera adding drag, and drag incurred due to varying air properties at different altitudes.

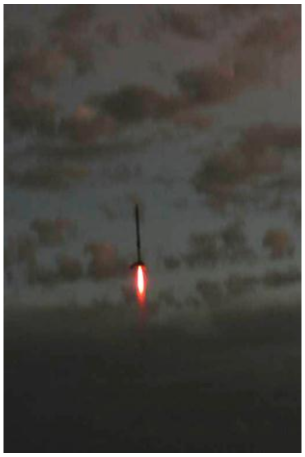

**Figure 22.** The APEX rocket moments after lift off.

# Analysis

As previously mentioned, the APEX rocket's actual maximum altitude came short of the Rocksim predicted maximum altitude by 29%. Because the weight of the rocket was only 0.1 lb over the input weight in Rocksim, this was likely due to added or unaccounted for drag on the actual rocket. There is a skin friction drag on the body tube of the rocket that was not put into Rocksim, as well as parasitic drag from the rail buttons, fin fillets, and camera shroud. It was also made apparent that there were components missing from the Rocksim model when the required added mass to the rocket was around 3.5 lbs (1590 g) to maintain stability and a maximum altitude under 1500 ft. However, due to a design flaw, none of the mass could be contained in the body tube. The nosecone was then used to hold about 2 lbs of the weighted beads, which brought the rocket to 5.6 lbs, just over the overall weight in RockSim of 5.5 lbs. This proves that there were several components unaccounted for in the simulation that not only added drag, but additional weight to the rocket as well. This was fortunate as it brought the rocket closer to its desired weight.

The stability margin of the rocket, defined as the difference in position between the center of gravity and the center of pressure, was taken into account when having to move the added mass to the nosecone. It was determined that putting the center of gravity higher on the rocket would actually increase the stability margin, a parameter best maximized. Weighted metal beads were put into the nosecone before it was taped shut and assembled with the rest of the rocket. There was much concern about the piston being able to push off the load of plastic army men, the parachute, and recovery materials, as well as the weighted nosecone, but during actual flight it performed perfectly. The avionics bay was programmed incorrectly, which caused the parachute to deploy at apogee, giving a long slow descent to the ground from over 1000 feet in the air.

As shown in Fig. 19, the rocket undergoes two disturbances before parachute deployment. We suspect that these two dips in altitude are in occurrence with each fin coming off the rocket, the first separating from its epoxy and the second sheared the balsa wood. The durability of the fins was a concern going into launch, and an analysis was performed afterwards. When using the RockSim model, the exact geometry of the fins was not given as an option so an approximation was used, which could lead to inaccuracies in the predicted loads on each fin.

# Thoughts & Conclusion

Though the launch was successful, there was room for improvement. Specifically, the avionics bay could have performed more ideally, as flight video was lost, and the ematch charges were swapped. The problem stems from lack of testing, the altimeter was expected to fire in the correct sequence but was not confirmed using the software, which is an option that would be utilized for another flight. The cameras have a DV/DC switch which, when switched to DV, records video and otherwise takes a still shot. One camera was on the DC setting and only got stills on the ground while the other did not record video because it was assumed a red light meant recording when, in fact, blue means recording.

On launch day, some last minute tasks needed to be completed which were not done due to lack of foresight. Weight needed to be added to the rocket to bring the RockSim simulation under 1500 ft, but the body tubes were not long enough to fit the necessary mass. A team member decided to put weighted beads in the nosecone, instead of the body, and to seal it with tape. Doing so allowed the mass to be increased while also increasing the stability margin. Also, the piston to push out the parachute and payload did not fit in the body tube. The piston needs to slide out smoothly, and so it was sanded pre-flight with a dremel until it worked.

There were first two mis-fires on the launch pad which were likely due to too much grease surrounding the motor, dampening the flammable material. A third trial with two igniters successfully resulted in lift-off. Another possible cause for the misfires is related to the humidity that was present at the launch site, making the grains less reactive.

The stability of the rocket was outstanding from a qualitative perspective. The rocket went straight up with very little spin. Near apogee, one of the fins came out of the rocket tube either from lack of epoxy or extreme amounts of stress. Shortly after, a second fin sheared off close to the body tube. This is exactly the hypothesis for a longer span, which predicts that the pressure would be too great and actually rip the fins off the rocket.