Badger Ballistics Participation in the WSGC[1] Collegiate Rocket Launch 2016[2]

Alex Strange, David Zeugner, Robert Bradley, Zach Petrie, Shawn Brouwer

Engineering Mechanics with Astronautics, University of Wisconsin-Madison

Abstract
This paper is a report of Badger Ballistics' participation in the Collegiate Rocket Launch Competition hosted by the Wisconsin Space Grant Consortium. The objective of this competition is to build a high power rocket depicting an accurate scale model of a launch vehicle used by private industry or government, and predict its launch apogee with minimal error. The vehicle's target apogee must fall between 2500 and 3500 feet. Our team chose to create a rocket replicating the German V-2 missile. Our design is most notable for our use of 3D printing for body components. At competition day, the team submitted an apogee prediction of 3300 feet and recorded an unofficial launch apogee of 2940 feet. Badger Ballistics achieved the third closest apogee prediction and placed fifth overall in competition.

Rocket Build

Design choice. The team decided to replicate the German Vergetungswaffe-2 or V-2 launch vehicle.

The V-2 was designed by Dr. Werner Von Braun, a German aerospace engineer and pioneer in rocketry. The rocket was the first artificial object to cross the boundary of space on June 20th, 1944 defined by the Karman line as 100 kilometers in altitude. After World War II, many V-2 rockets were salvaged by the allied powers and launched for testing until 1952.[1]

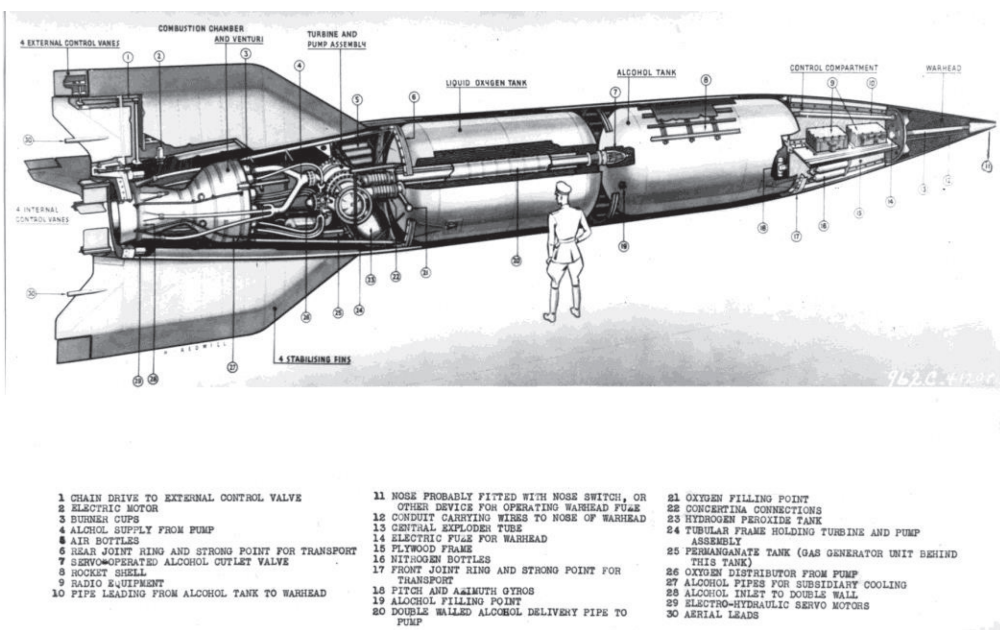


Fig 1: Diagram of V-2 internal features [2]

[1] Our team thanks the Wisconsin Space Grant Consortium for their generous donation.

[2] Proceedings written by David Zeugner.

The real V-2 was 46 feet in length, 5 feet 4 inches in diameter, and 11 feet 8 inches in maximum wingspan. A fully-fueled V-2 weighed around 12,500 kg not including its payload. The launch vehicle reached a cruising altitude of nearly 3600 mph.

The Germans typically loaded a 1000 kg amatol warhead into the launch vehicle's nose while using the rocket as a weapon. Amatol is composed of TNT and ammonium nitrate.

Team's scale. The team recreated the V-2 to a scale of roughly 1:15. Our final build was 35.6 inches long, had a maximum body diameter of 3.8 inches, and a wingspan of 9 inches.

Adjustments from real V-2. To maintain stability, the lack of an explosive amatol warhead warranted a heavy ballast to be added to the nose cone. This weight composed of about one kilogram of lead shot. This mass raised the stability of the rocket from 0.6 cal to an acceptable 1.0 cal. The measure of stability used is the distance between the center of gravity and center of pressure divided by the rocket diameter. A positive stability value was obtained with a center of pressure aft of the center of gravity.

The gas rudder control surfaces shown in the V-2 diagram were not built into the team's model. The V-2 recreation had no thrust vectoring ability and relies solely on its static stability to maintain a straight flight trajectory. The German V-2, on the other hand, needed control surfaces to direct its flight over a long burn time and accurately travel to a target.

Rudder geometry was somewhat accounted for in the team's fin design. Small protrusions from the main wing near the rocket body base were included.

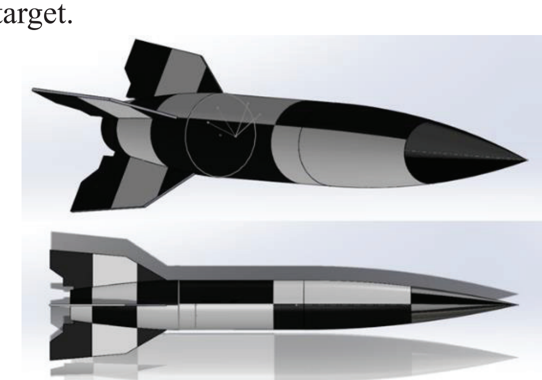
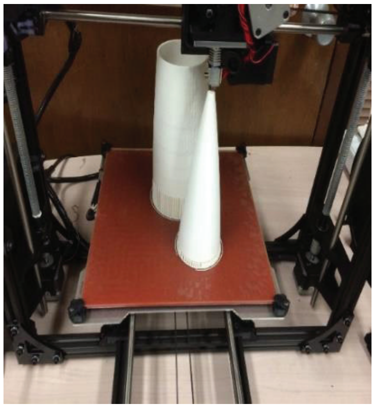


Fig. 2. SolidWorks model of team's V-2 recreation

Material choice. Four main body components composed of ABS plastic: front nose cone, back nose cone, middle body tube, and boat tail. The ABS parts cracked on their outside surfaces while cooling shortly after being printed. Epoxy was coated onto each part to fill in these cracks. The motor casing was made from blue tube. Fins and other internal components such as bulkheads were cut out of eighth inch thick plywood. The parachute and electronics bay was secured with a combination of low-grade steel fasteners, threaded rod, hex nuts, and shock cord. All internal components including the nuts and fasteners were sealed with epoxy.

Fabrication. The four main body components were 3D printed using a Tazbot 5 printer. Each component took roughly one full day of continuous printing to complete. This method of construction was chosen for its ability to recreate the contours of the V-2 launch vehicle with ease.

Every part of the rocket was modelled in SolidWorks.



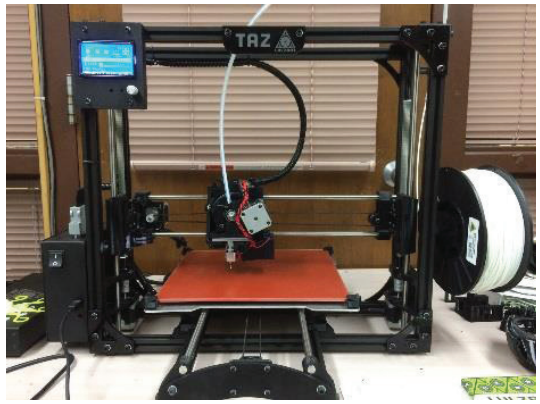


Fig. 3 and 4. Tazbot 5 printer in action

A dxf file for each part cut from plywood was obtained from a corresponding SolidWorks part file. Using Adobe Illustrator, each dxf file was arranged on a virtual artboard and an accompanying print job was sent to a laser cutter to be cut.

Epoxy was used to mate each part together in the final rocket assembly.

The electronics bay was designed to sit inside the back nose cone during flight. It screws into place at three points. Threaded rods were fed through each point, two of which mate with a bulkhead and the last with the nose cone.

A 48 inch parachute was attached to the same bulkhead in the back nose cone fastened to the electronics bay, as well as to another bulkhead fixed to the middle body tube. At apogee, the rocket is intended to break between the back nose cone and middle body tube, releasing the parachute.

A piece of blue tube was used to house the motor. The blue tube was glued to the bulk head in the middle body tube and boat tail. Fins fit between slots in the boat tail and were mated to the outside of the blue tube with epoxy.

Fig. 5 and 6. Bulkhead in the middle body tube (left) and internal boat tail structure (right)

Electronics Bay. A Stratologger was used as our flight computer, altimeter, and barometer. A 1.5 volt battery runs the Stratologger. The altimeter reads altitude by air pressure.

Simulation

Three methods were used for flight simulation. The first was through OpenRocket. A model of our launch vehicle was created in OpenRocket. The software predicted the rocket would reach an altitude around 3130 feet.

MATLAB scripts were written by the team to make a flight performance estimation. The first script involved an iterative method similar to Euler's time step curve approximation formula with linear segments. Calculation inputs included the rocket's initial and final mass, motor thrust profile, and drag coefficient. The script gave us an estimation of 3450 feet.

The last script involved a series of ordinary differential equations. A prediction of 3296 feet was taken from this script.

Wind was not accounted for in any simulation ran by the team.

Competition Performance

The team agreed on an apogee prediction of 3300 feet. During launch, our rocket reached an apogee of 2940 feet as measured by our Stratologger. The team was unable to get an official apogee reading from a Raven-3 flight computer added to our electronics bay. This prediction was the third best value at competition. Badger Ballistics placed 5th place in the overall competition.


Fig. 7: Finished high power rocket

References
A-4/V-2 Resource Site. Retrieved from: http://www.v2rocket.com/.
U.S. Army V-2 cutaway drawing showing engine, fuel cells, guidance units and warhead. (1945, August 1). *U.S. Air Force.* Retrieved from: https://commons.wikimedia.org/wiki/File:Esquema_de_la_V-2.jpg.