MIDWEST HIGH-POWER ROCKET COMPETITION

ROCKET-MEN

PRELIMINARY DESIGN REPORT

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EXECUTIVE SUMMARY

Jacob Hart-Lane

The Wichita State Rocket-Men are a Senior Design group at Wichita State University. Founded in August 2015, the group determined that they wanted to participate in the Midwest High Powered Rocketry Competition. As part of the Senior Design process, the group divided the design work up into five subsections: Aerodynamics, Structures, Stability and Control, Propulsion, and Payload. Each of the five group members was the head of one subsection, and each group member also had at least one additional section that they acted as assistant to.

During the conceptual design phase, the group considered several potential solutions to the Active Drag Challenge. In addition to what we have been calling “speed brakes” we also considered inflatable bladders, deployable parachutes and full body tube length speed brakes, designed for a sudden stop. Ultimately it was decided that the best idea was our first, a set of speed brakes deployed into the air flow to induce increased drag, and achieve the desired 75% altitude. The drag system would be placed above the engine, but below the center of gravity to insure stability after deployment.

DESIGN FEATURES OF ROCKET AIRFRAME

Body Tube Structural Analysis

Dustin Jacobson

For the longitudinal and hoop stress in the body sea level pressure will be used. Since we will be launching the rocket in at least Kansas and Minnesota where the pressure is lower this will give us a built in safety factor. Also since the radius is much greater than the thickness the rocket can be assumed to be a thin walled member. Using the equations listed below the hoop stress was calculated. [9]

$$\sigma_L = \frac{Pr}{2t}$$
$$\sigma_H = \frac{Pr}{t}$$

Assumptions for hoop and longitudinal stress:

1. Thin walled member due to the radius being much greater than the thickness
2. No end effects on the tube.
3. Pressure is 14.696 psi inside the rocket body

As stated above a pressure of 14.696 psi will be used as well as a thickness of .079 inches and a mean radius of 1.4605 inches. Using these numbers, a longitudinal stress of 136 and hoop stress of 272 psi was determined. For phenolic/fiberglass tubing the ultimate compressive strength is 109,000 psi[10] giving us a factor of safety of 801 for longitudinal loading.

Fin Analysis

Tarun Bali

The fin geometry was very poorly constrained during the initial stages of design. Several geometries seemed like equally viable options. However, as the design matured, limiting constraints began to dictate the shape and configuration of the fin set.

The following aspects of the fin geometry were taken into account while arriving at an ideal fin set configuration:

- Number of fins
- Root chord
- Tip chord
- Fin height
- Sweep length
- Fin thickness

Considering the Barrowman's report, a 4-fin configuration was chosen over a 3-fin configuration that yielded the same Center of Pressure (CP). This was because a 4-fin configuration resulted in slightly higher altitude predictions. To ensure easy and quick construction, it was decided to use flat plates for fins as opposed to an airfoil cross-sectional fin.

One of the primary concerns was the brake flaps. The team was concerned that when activated, the flaps might create a region of separated flow that may engulf the fins. This meant the rocket would quickly become unstable. Therefore, the fin height was increased to ensure that the fins were not completely in the separated flow. In order to maximize the area of the fin available outside the separated flow region, a trapezoidal fin shape was decided upon over the original choice of a simpler right triangular fin shape. Finally, a sweep was introduced to push the CP towards the tail.

An open-source program, OpenRocket, was used to run a few simulations. An optimization drill was run adjusting the aforementioned fin characteristics to maximize predicted altitude. The obtained fin configuration was used as a guideline to recalculate the CP for an easier to construct fin configuration.

Following these exercises, the final fin configuration was achieved.

Brake Flap Analysis

Dustin Jacobson (Structures); Ryan Miller (Aerodynamics)

The aerodynamic structure of the drag system consists of four convex circular pedals 3 inches long and 0.7 inches wide each with a radius proportional to the rocket body tube (3 inches). While the drag system is inactive the drag pedals are stowed flush with the body tube. When activated, the pedals rotate about forward hinges symmetrically like an umbrella, effectively expanding the radius of a section of rocket body tube.

A similarity was found to exist between the two dimensional flow around a circular cylinder and the convex pedals from data provided by Anderson [xx]. At a Reynolds number of 1E05 separation on the cylinder begins at the middle, the maximum dimension normal to the flow, creating a separation zone proportional to the diameter of the cylinder, thus mimicking half of a convex circular arc. The drag coefficient produced under these conditions is 1.2 very close to that of a flat plate (1.28). At higher Reynolds numbers separation on the cylinder is delayed aft of middle, minimizing the separation zone, decreasing the drag coefficient. Sharp corners and geometric discontinuities of the convex pedals ensure flow separation. Therefore, the speed brakes can be approximated as flat plates.

Wind tunnel drag coefficient data for flat plate speed brakes at transonic speeds was obtained from Vick [1]. A series of rectangular flat plates with aspect ratios (A/R) ranging from 0.25 to 4, where A/R was calculated by dividing the width of the speed brake by its radius, were oriented at angles of attack ranging from 15 to 90 degrees at Mach numbers ranging from 0.2 to 1.3. The data shows that drag coefficients for the speeds brakes range from 0.35 to 1.78 depending on angle of deflection, Mach number, radius of the speed brake and A/R.

Our speed brake pedals have an A/R of 0.23 which coincides with 0.25 aspect ratio data provided by Vick. Limited data for an A/R of 0.25 is provided, but ample data is provided for an A/R of 0.50. Comparing the data for 0.25 and 0.50 aspect ratios shows that the 0.25 A/R produces a drag coefficient eight percent higher on average than the 0.50 A/R. For the purposes of preliminary design 0.50 A/R data was used to create a basic drag coefficient model to size the speed brakes Figure [1]. As data is collected during test rocket flights, the drag model for our controller will be improved and updated.

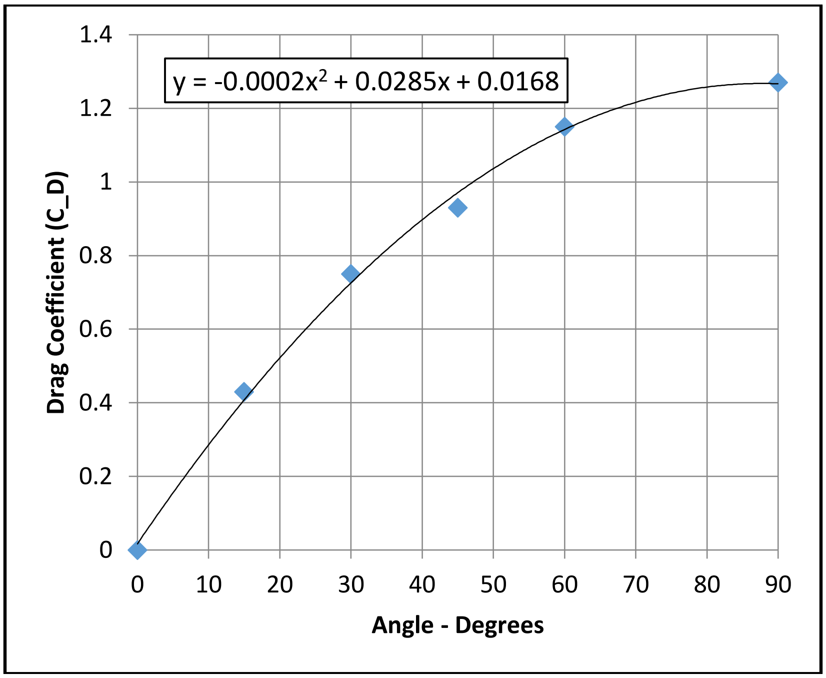


FIGURE 1: DRAG COEFFICIENT WITH RESPECT TO SPEED BRAKE ANGLE OF DEFLECTION (RYAN MILLER)

Pedal analysis

Bending Stress in the pedals was done using the bending stress equation [9]. Since the pedal is supported by the rocket body and a connecting rod it will be analyzed as a dual supported beam instead of a cantilevered beam.

$$\sigma_{BM} = \frac{M * y}{I}$$

$$M = \frac{F * L^2}{8}$$

$$I = \frac{1}{12} * b * h^3$$

Assumptions that were made for bending stress in the pedals are:

1. The flap is considered a rectangular beam that is supported at both ends

2. The force is to be a load distributed equally across the beam.

Using a value of 10 pounds of force for the drag and an area of 2.1 in.^{2} various stresses can be calculated. In order to get these values, the thickness of the flap was varied from .1 to .25 inches at .025 inch increments. Also the width of the flap was varied from .1 to 1.1 inches by increments of .1 inches. In order to allow for a greater number of materials to be used as well as a larger safety factor all stresses over 50,000 psi were eliminated for consideration. Since .125 is a fairly common thickness for stock materials I chose that number to further narrow down the size of the flaps. Finally, a flap that is 1x4.5x.125 inches in size was selected. This will allow us to have the easiest numbers for manufacturing and should lead to a more consistent product while still getting the drag needed. With this size the stress found in the flap at full deployment at burnout would be 35,000. Using this number and a safety factor of 3 a material was chosen from the MatWeb database that would fit these requirements.

Conical Boat-Tail Analysis (Ryan Miller)

During conceptual design, minor optimization of the rocket body was conducted to reduce drag with the intention of improving rocket performance to account for payload weight uncertainties. Initial models created in OpenRocket predicted that incorporating a boat-tail offered the greatest drag reduction of any modification. The boat tail taper was kept below 12 degrees as recommended by Raymer [1]. Results from a rocket simulation program we designed (See XYZ) and OpenRocket predicted a 20% reduction of the coefficient of drag by adding a boat tail.

Nose cone Analysis

Ryan Miller

Initially, a Von Kármán nose cone was selected for our rocket during conceptual design since rocket simulations predicted achieved speeds near Mach 1.5 and the Von Kármán provides excellent performance in the transonic regime. However, as our design progressed our rocket weight increased, and rocket max speed predictions dropped below Mach 0.8. We opted to incorporate an ogive nose cone instead of the Von Kármán due to commercial availability. Further aerodynamic optimization of the nose cone is not critical to the mission, and therefore detailed analysis was not completed.

Propulsion System Specifications

Jacob Hart-Lane

The engine is the heart and soul of the rocket. You can design the best payload in the world, and the most aerodynamic body ever envisioned, but none of it will ever make it off the ground without the correct rocket engine. With the major mission of this rocket being an altitude goal, the engine selection becomes even more critical. Given the minimum altitude requirement of 3000 feet and the team goal of achieving the bonus points given by 5000 feet, multiple rocket engines were evaluated. Impulse classes ranging from H to K were evaluated. A conceptual rocket with an estimated weight was used to generate flight profiles for a variety of engines using derived equations for velocity and position versus time. The analysis eventually led to the selection of the Cesaroni J580 engine. The J580 is 38 millimeters in diameter and 51 centimeters long (thrustcurve). It has an average thrust of 577 Newtons and a burn time of 1.6 seconds.

DESIGN FEATURES OF ELECTRONICS/PAYLOAD

Drag System

Our drag system consists of four speed brakes connected to a linear actuator which is controlled by the Arduino Due controller, and powered by a Tenergy 12v Li-ion battery. Furthermore, an accelerometer and an Inertial Measurement Unit will be connected to the Arduino controller to record real time data to accurately extend the speed brakes to the desired extent. The figure below shows the non- linear rate of change between the displacement of the linear actuator and the deflection angle of the speed brakes.

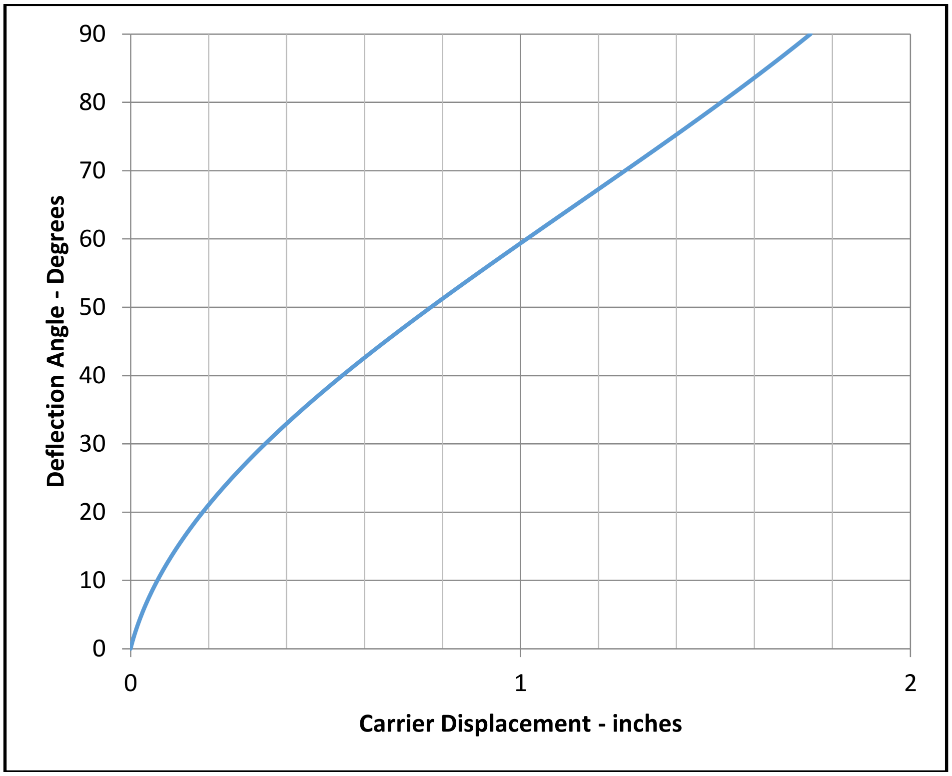


FIGURE 7: SPEED BRAKE ANGULAR DEFLECTION WITH RESPECT TO LINEAR ACTUATOR DISPLACEMENT. (RYAN MILLER)

Recovery System

Jacob Hart-Lane

The recovery system will feature a dual deployment. The first parachute, the drogue, will be significantly smaller than the main parachute, and will slow the rocket down some, while reducing drifting due to the wind. The drogue will be deployed via the motor ejection charge at apogee. The main parachute will be large enough to significantly slow the rocket for a safe landing. The main chute is stored above the payload bay, and will be deployed via an altimeter controlled ejection charge.

Electronics

Linear Actuator for Drag system

The maximum force acting on the drag pedals was calculated to be 10 lbs and the stroke required is 1.37 inches. Therefore, linear actuator was a better option since they provided a wide range of the required force and were simple to assemble and compatible with the Arduino controller as compared to the motor connected with a corkscrew configuration. The power consumption of the actuator was calculated from equations listed below.

$$P = Fv$$
$$mAh = Wh\frac{1000}{V}$$

The linear actuator selected was Firgelli P16 (64:1) with a maximum stroke of 1.96 inches. The power consumed by the actuator is 59 mAh, given in table 2.

Time (s)	Drag (N)	Power Consumption (W)	Power (Wh)	Power (mAh)
1.7-5	32.31	581.2	0.016	45.74
5.1-8	18.55	170.9	0.14	11.87
8.1-11	5.12	22.39	0.018	1.55
11.1-13.1	0.51	0.798	0.00046	0.038
			Total	59.20

Table 2. POWER CONSUMPTION TABLE *(KURUSH TAVADIA)*

Arduino Controller

After further analysis of the controller, the requirements and constraints were optimized. The controller should be able to take two inputs from the accelerometer and nine inputs from the inertial measurement unit (IMU). The output needs to be only to the linear actuator. Since, we need near real time response but are not certain on how much memory the code will take, Arduino Due was selected. Arduino Due gave the highest processing speed and flash memory at reasonable voltage and cost.[2]

Inertial measurement Unit & Accelerometer

It is important to know whether the rocket is accelerating/ decelerating, orientation, barometric pressure and temperature during the mission. A 10 degree of freedom Adafruit IMU was chosen so it can record data such as angular rate, acceleration and orientation (position), barometric pressure and temperature.

The maximum force acting on the rocket due to acceleration is 16 g. An LIS331HH accelerometer was selected get more accurate data during burnout and compare it with the IMU data for accuracy.

Altimeter

In addition to the altimeter two provided by the competition, an Entacore AIM 3 altimeter will be used for deploying the main parachute at the desired altitude. It should be noted motor ejection will also be used.

Tarun Bali

Risk Mitigation (Tarun Bali; Kurush Tavadia; Jacob Hart-Lane; Dustin Jacobson; Ryan Miller)

The minimization of risks, and possible surprises, was a primary objective of the team from day one. The following measures were taken to mitigate risk:

The use of a drogue and main parachute

Due to spatial limitations in the payload, the team was inclined to opt for a single parachute. However, based on past experience, the use of a drogue parachute and a main parachute separately was decided on to prevent damage to the rocket in case of a parachute failure. The use of a drogue would also buy the team critical time to prepare for the second launch.

Active drag system

The rocket motors do not perform accurately enough to succeed using a passively controlled drag system. For example, a 10% difference in output from the propellant between the two flights could result in failure to accurately achieve the desired apogee.

An active drag system that compared the rocket's vertical velocity and location in real time to adjust the angle of brake-flap deflection would help achieve the desired apogee much better.

Placement of Flap Hinge

Initially, placing the brake-flap hinges at the trailing edge was considered as this configuration would assist in activating the brake flaps quickly. However, the placement of the hinges was moved to the leading edge so that if the actuator failed for any reason, the flaps would return to the deactivated state and not be in a constant state of high stress and low stability.

Factor of safety

A high factor of safety was used in the design of every component to prevent damage due to unexpected and unforeseen loading.

Flow separation & Flap-Fin Interference

As discussed earlier, flow separation due to the deflection of the brake-flaps was a cause for concern. In order to minimize, the flap-fin interference, the fins were rotated about the longitudinal axis by 45° so as to minimize flow separation effects.

Considering a 15° flow separation angle at subsonic velocities, it was determined using a theoretical model that in a worst case scenario, the fins would be in the flow at an angle of attack of 17°.

The rocket will be tested in the wind tunnel in order to gain a better qualitative understanding of the air-flow around the brake-flaps and fins, and to determine that the theoretical model is, in fact, a conservative estimate.

Ejection charge testing

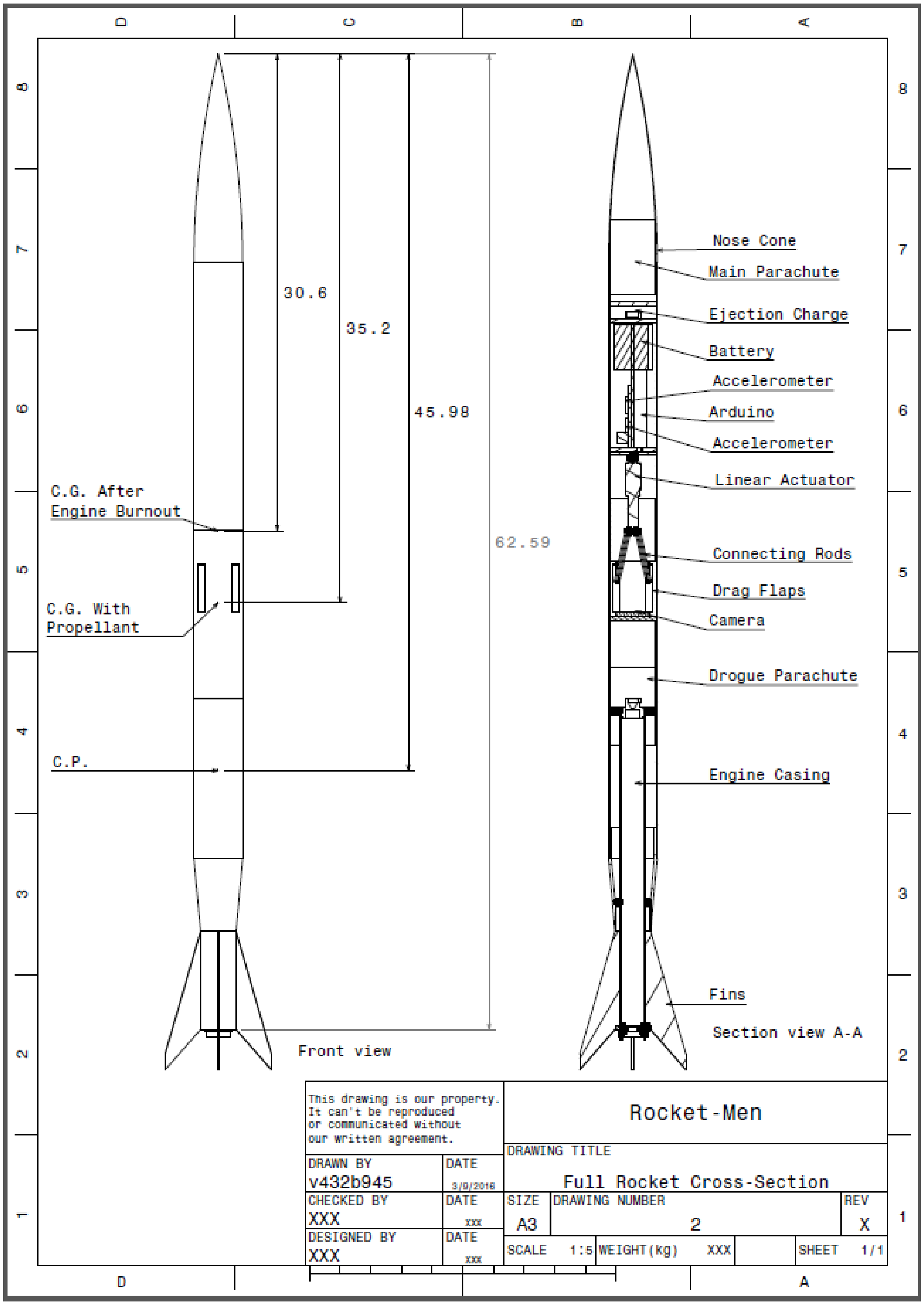
The ejection charge will be tested on the ground to reduce chances of recovery system failure during the actual flight.

Multiple test runs

The team also plans on carrying out several test runs prior to the actual competition in order to detect and address any bugs in the rocket design.

ROCKET DIAGRAM

Dustin Jacobson



Assembly instructions

Tooling Assemblies

Fin Tooling Assembly

1. Assemble all Fin Tooling Assembly components as listed in the parts inventory
2. Epoxy all components together, as shown in drawing T19

Flap Hole Tooling Assembly

1. Assemble all Flap Hole Tooling Assembly components as listed in the parts inventory
2. Epoxy all components together, as shown in drawing T25

Flap Cutout Tooling Assembly

1. Assemble all Flap Cutout Tooling Assembly components as listed in the parts inventory
2. Epoxy all components together, as shown in drawing T25

3” Body Tooling Assembly

1. Assemble all 3” Tooling Assembly components as listed in the parts inventory
2. Epoxy 1 3” body restraint to the 3” body tooling base
3. Epoxy 4 external alignment struts to Tooling Base
4. Epoxy the tops of the Alignment struts to the 3” body restraint

2.13” Body Tooling Assembly

1. Assemble all 2.13” Tooling Assembly components as listed in the parts inventory
2. Epoxy 1 2.13” body restraint to the 2.13” body tooling base
3. Epoxy 4 external alignment struts to Tooling Base
4. Epoxy the tops of the Alignment struts to the 2.13” body restraint

Flab body Coupler jig

1. Assemble all Upper body coupler jig Tooling Assembly components as listed in the parts inventory
2. Epoxy 4 internal alignment struts to coupler dummy bulkhead

Lower Body Coupler Jig

1. Assemble all lower body coupler jig Tooling Assembly components as listed in the parts inventory
2. Epoxy 4 internal alignment struts to coupler dummy bulkhead

Upper body Bulkhead jig

1. Assemble all Upper body tube bulkhead jig Tooling Assembly components as listed in the parts inventory

2. Epoxy 4 internal alignment struts to coupler dummy bulkhead

Flap body Bulkhead jig

1. Assemble all flap bulkhead jig Tooling Assembly components as listed in the parts inventory
2. Epoxy 4 internal alignment struts to coupler dummy bulkhead

General Pre-Assembly Steps

1. Using the 48” x 3” diameter body tube, cut body tubes that are 17.12”, 10.83”, and 10.28”
2. Using one 9” x 3” diameter Coupler tube, cut an 8” long coupler
3. Using one 9” x 3” diameter Coupler tube, cut a 5” long coupler
4. Using the 12” x 2” diameter body tube, cut the lower body tube to 8.3”
5. Using the 36” x 1.5” diameter tube, cut an inner engine tube to 20.67”
6. Using the Flap cutout jig, using the excess from the 48” x 3” diameter body tube, cut out drag flaps
7. Using Fin cutout template, cut out 4 fins from the 1/8” by 1 sq ft fiberglass plate
8. Using Flap stiffener cutout template, cut out 4 stiffeners from the 1/8” x 1 sq ft fiberglass plate
9. Using Flap connecting rod cutout template, cut out 4 connecting rods from the carbon plate
10. Use scissors to cut the 24 foot shook cord into two sections, each 12 feet long

Wind Tunnel Model Assembly (WTM)

1. Assemble all WTM Assembly components as listed in the parts inventory
2. Cut the 2" x 2" x 72" pine board into three parts:
    3. 41" Center rod fore (CRF)
    4. 11" Center rod aft (CRA)
    5. 03” Mounting Board
6. Finish cutting mounting board as per Drawing WT-17
7. Epoxy the mounting board onto the CRF 20.625” from the front face
8. Drill holes on the CRF as shown in Drawing WT-13
9. Drill holes on the mounting board as shown in Drawing WT-17
10. Drill holes on the aft face of the CRF as shown in Drawing WT-13
11. Drill holes on the front face of the CRA as shown in Drawing WT-14
12. Use a band saw to cut slots in the CRA as shown in Drawing WT-14
13. Glue in the connecting and alignment rods into CRF
14. Glue the aft ends of the connecting and alignment rods into the CRA holes
15. Glue the Upper body foam onto the CRF
16. Glue on the Nose Cone to the CRF
17. Glue Conical boat tail foam onto CRF
18. Glue in the leading Fin set, and then the trailing Fin set into the CRA Fin slots
19. Adhere the aft foam sections to the CRA and Fins

Upper Assembly

1. Assemble all Upper Assembly components as listed in the parts inventory
2. Sand and clean inside of Upper Body Tube (17.12”) where the bulkhead is to be attached
3. Place Bulkhead #1 on 3” Bulkhead Tooling Assembly. Be certain the actuator divot is facing the tooling.
4. Slide Upper Body tube (17.12”) into 3” Bulkhead Tooling Assembly
5. Apply a fillet of Epoxy to edge of the top of the bulkhead. Allow to dry
6. Epoxy Launch rail button to Upper tube assembly

Payload Assembly

1. Assemble all Payload Assembly components as listed in the parts inventory
2. Epoxy one Payload mounting bulkhead to the end of the Payload board using Payload Board mounting tooling
3. Place a weight on top of tooling to insure compression.
4. Repeat Step 2 with the opposite end of the Payload Board
5. Epoxy thickening board to bottom of Payload board.
6. Screw Ardurino, and accelerometers to Mounting Board as shown in Drawing 5
7. Place a ring of Epoxy on the Ejection charge tube, be sure to *not* fill in the hole, and adhere the Ejection charge tube to the upper plate of the Payload Board

Flap Assembly

1. Assemble all Flap Assembly components as listed in the parts inventory
2. Insert Flap Assembly Body Tube (10.83”) into Flap hole jig
3. Cut flap holes (4x). Clean tube
4. Sand coupler and body tube bonding surfaces
5. Using the 3” tooling assembly with the coupler height attachment, Epoxy the 5” coupler to the Flap Assembly Body Tube
6. Using the 3” tooling assembly and the flat bulkhead height attachment, Epoxy a bulkhead to the Flap Assembly Body Tube
7. Epoxy Flap stiffener to flap (4x), and allow to dry
8. Epoxy Flap flexure to flap/stiffener assembly (4x), and allow to dry
9. Epoxy Flap flexure to body tube (4x), and allow to dry
10. Epoxy Launch rail button to Flap tube assembly

Lower Assembly

1. Assemble all Lower Assembly components as listed in the parts inventory
2. Using the 3” tooling and lower coupler height attachment, epoxy the 8” coupler to the lower main body tube
3. Place Lower body tube (outer radius 1.16”) in fin slotting tooling.
4. Use the Dremel Tool to cut 4 slots 0.125” by 6.3”
5. Using Centering ring tooling, epoxy the mid-length centering ring to the inner tube

6. Epoxy Lower centering Ring to aft of Inner Tube
7. Epoxy Upper Centering Ring to Fore section of Inner Tube
8. Allow Inner Tube Assembly to dry
9. Layup Boat Tail
10. Insert Boat Tail inner tooling piece.
11. Epoxy Lower Body tube to Boat Tail section
12. Remove Boat Tail inner Tooling piece
13. Epoxy Lower Main Body Tube to Boat Tail Section
14. Epoxy inner tube to Lower Tube assembly
15. Epoxy Fin into fin slot (4x)

Material Handling Procedure

In order to insure a safe and responsible construction and launch phase a number of procedures will be in place. At all times in the lab and during launches a first-aid kit will be available for use. Also when using power tools team members will use safety glasses. When handling epoxy and other substances that undergo a chemical reaction latex gloves will be used. While in the lab the rocket engines will be stored in a fireproof cabinet. Students are also required to read and understand the Wichita State University Lab Safety Manual that is presented in class before working on the rocket. All unused epoxy and other hazardous waste will be disposed of in a hazardous waste drum. When painting the rocket make sure that the area is well ventilated. Also when painting or cutting composite materials a respirator should be worn.

Pre and Post Launch Procedures (Jacob Hart-Lane)

General Guidelines:

1. Keep safety in mind and use common sense when handling rocket components.
2. Refer to material handling procedures for hazardous materials.

Pre-Launch

1. Assemble the rocket
2. Set Payload to either 1st or 2nd flight condition
3. Check C.G. position is correct before taking to RSO for approval.
4. Turn the main payload on.
5. Just before rocket is placed on the launch pad, turn on the Altimeter 2 and radio tracker.

Post-Launch

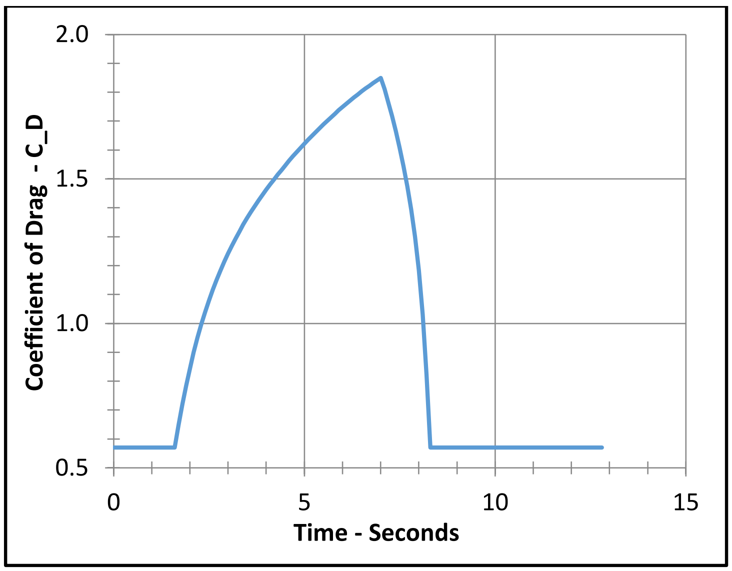
1. Endeavor to make visual contact with the descending rocket
2. Utilize radio tracker to verify direction, especially when visual contact is lost
3. If driving is necessary for retrieval, passengers will respect all rules of the driver, as well as safe driving practices.
4. Photographs are to be taken of the landed rocket
5. Return rocket to launch site for altitude evaluation

6. If desired or necessary, repeat pre-launch procedures for additional flights

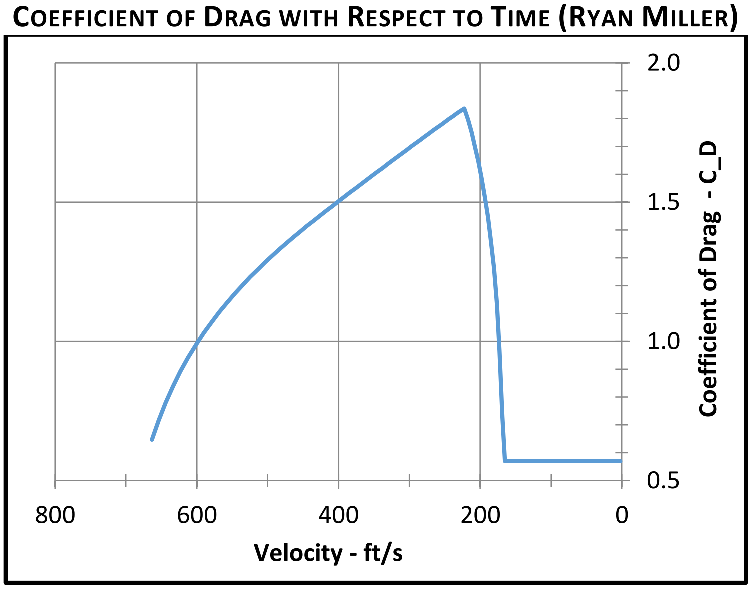
ANALYSIS OF ANTICIPATED PERFORMANCE

Drag System (Ryan Miller) and (Jacob Hart-Lane)

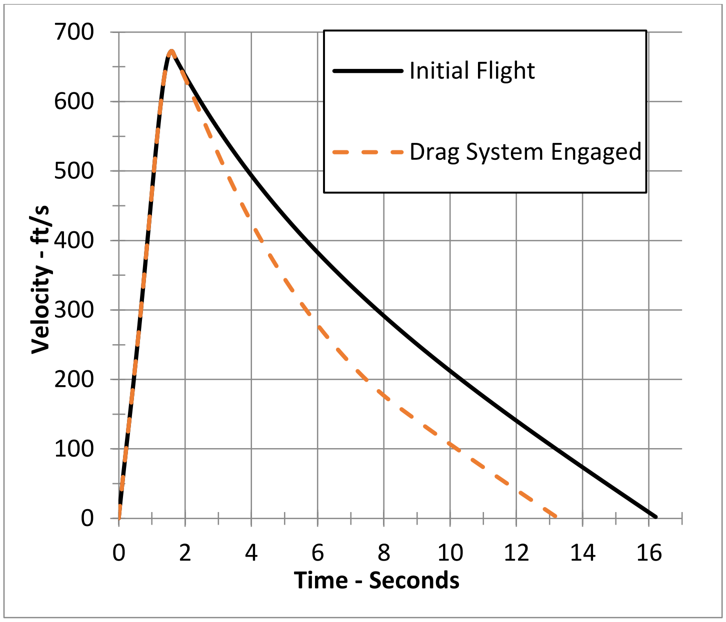
We created a rocket simulation program to design our rocket. Starting with a basic free body diagram of the rocket in flight and summing the forces we derived a general equation. Next, we applied numerical method approximations to obtain algebraic solutions for velocity and altitude. Initially, we input the equations in excel using a moderate time step of 0.1 seconds and we assumed the coefficient of drag, temperature, density, thrust, and rocket mass were constant. Improvements to the model were introduced over time and



COEFFICIENT OF DRAG WITH RESPECT TO TIME (RYAN MILLER)



COEFFICIENT OF DRAG WITH RESPECT TO VELOCITY AFTER BURNOUT (RYAN MILLER)



Velocity with Respect to Time (Ryan & Jacob)

Launch Analysis

Having selected the appropriate engine, propulsion turned its attention to modeling the launch and flight conditions with more realistic assumptions then were used in the conceptual phase. Taking the J580 engine thrust curve data from Thrustcurve.org, a curve fit was used to generate a thrust versus time equation. Atmospheric data was also used to generate an equation for the change in density with altitude. These equations were incorporated into the flight performance spreadsheet. As design work progressed, weight estimate became more fine-tuned, and allowed for more accurate altitude predictions. Since all engine manufacturers state that their engines may perform at plus or minus 10% of their stated thrust, the J580 was modeled performing at plus and minus 15% of the average thrust. Finally, the switch was made from sea level starting conditions, to those found in Minnesota, the sight of the competition launch.

The results of these calculations can be found in fig X. As can be seen, the more recent predictions no longer call for the rocket to break 5000 feet unless it is performing extraordinarily well. On the other hand, all calculated values indicate that the rocket will reach the minimum altitude of 3000 feet, even if the engine is underperforming. Given an engine with a typical thrust curve, the rocket will reach an altitude of 600 feet after 1.6 seconds of burn time. The predicted apogee is approximately 4400 feet above ground level. Peak velocity is estimated to be 620 feet per second at burn out.

	J580	**J580 +15%**	**J580 -15%**
Apogee (Ft)	4416.4	5328.8	3491.4

Fig X

Flight Analysis (added to launch analysis)

Recovery Analysis (Kurush Tavadia)

For selecting the right size, the descent velocity and the impact velocity were calculated for a variety of commercially available parachutes. According to Tripoli Standard, the maximum allowable descent velocity should be 20 ft/s. The equation listed below was used to calculate the descent velocity. [13]

$$v\_dsc = \left(\frac{2 * g * \mathrm{m}}{\rho * Cd * S}\right)^{1/2}$$

Based on these calculations and Tripoli requirements the main parachute with an outer diameter of 7 feet, descent velocity of 15.31 ft/s and a drogue with an outer diameter of 1.5 feet, descent velocity of 59 ft/s was selected, refer table 3.

Note: The descent velocity was calculated for the individual parachutes, but in reality it will be lower because of both the parachutes.

Outer D (ft)	Inner D (ft)	Area S (ft^2)	V (ft/s)	Impact (lbf)	Tug (lbf)
1.5	0.33	1.68	71.91	-334.99	-41.64
2	0.41	3.01	53.75	-250.40	-47.28
2.5	0.41	4.78	42.67	-198.76	-50.72
3	0.66	6.73	35.96	-167.49	-52.81
4	0.66	12.22	26.67	-124.25	-55.69
4.5	0.83	15.36	23.79	-110.83	-56.59
5	1	18.85	21.48	-100.06	-57.30
6	1.16	27.22	17.87	-83.27	-58.42
7	1.33	37.09	15.31	-71.32	-59.22

Table 3. PARACHUTE SIZING TABLE *(KURUSH TAVADIA, JACOB HART-LANE)*

Stability Analysis (Tarun Bali)

The stability of the rocket was determined separately for the different phases of the mission. During the initial engine burn, the rocket maintains a traditional configuration from an S&C standpoint. The Barrowman's equations were used to determine the position of the Center of Pressure (CP).

Following the engine burnout, the drag-flaps are extended outwards up to an estimated 35° angle. The purpose of the preliminary design was to ensure that the rocket would remain stable during this phase of the mission under all circumstances. In order to do so, the normal forces were calculated on the:

- Sections of the rocket body
  - Nose (Ogive)
  - Conical boat-tail
- Brake flaps, and
- Fins

For the sections of the rocket body, the normal forces were calculated using the formula:

$$n(x) = \rho V_0 \frac{\partial}{\partial x}[S(x) \cdot \mathrm{w(x)}] = \rho V_0^2 \alpha \frac{\partial S(x)}{\partial x}$$

$$N(x) = \int n(x)\mathrm{dx}$$

To err on the conservative side, the brake flaps were assumed to be flat plates. The normal forces generated by the flaps were calculated using fundamental flat plate aerodynamics. Note that though the net normal force generated by the flaps at 0° angle of attack is theoretically zero, an increase in angle of attack results in the introduction of a net normal force due to the difference in the angles of attacks of diametrically opposite flaps. The normal forces on the fins were calculated using the same technique. The CP was determined by combining the net forces calculated above.

Addressing Wake Interference

Wake interference was identified as a potential threat to the rocket's stability. In order to minimize the adverse effects, the fins were offset from the flaps by an angle of 45°. Additionally, the width of the brake-flaps was reduced by 30% in order to further minimize wake interference effects.

That being done, during the calculation of the rocket CP, it was assumed that the entire fin portion radially within the distance of brake-flap extension generated no usable normal force to stabilize the rocket. With this limiting condition, the fin was redesigned to have enough surface area outside the separated flow in order to maintain stability.

To be conservative in the design estimates, it was decided to use a ballast in the nose cone in order to move the CG upwards, and ensure that the brake-flaps were aft of the CG. This was done because without the fins to correct the attitude of the rocket, the CG trailed the CP by several calibers.

Once the normal forces on the nose cone and the flaps were calculated, the moment about the CG was calculated, and consequently so was the moment coefficient. A ballast weight of 10 oz was determined necessary to place the CG at a favorable location to have a stable flight in all configurations of flight.

Environmental Conditions Analysis (Ryan Miller)

Plots (Ryan Miller)

BUDGET

#	Item (equipment, materials, parts, laser cutting, etc.)	Cost	Quantity	Total
1	Phenolic Airframe Tubing Inner Dia 1.525" (inner tube)	$13.99	1	$13.99
2	Heavy Duty 72" rip-stop nylon conical parachute, ~14" spill hole	$106.95	1	$106.95
3	18" rip-stop nylon conical parachute, ~4" spill hole	$18.95	1	$18.95
4	Linear Launch Rail Lugs (2 lugs/pkg)	$5.95	1	$5.95
5	CESARONI - P38-6XLG SMOKY SAM (J580)	$72.44	10	$724.40
6	CESARONI 38MM 6XL-GRAIN CASE	$59.16	2	$118.32
7	KEVLAR CORD 1500# $0.92/ft	$0.92	24	$22.08
8	G10 Fiberglass Sheet 1/8" x 1 sq ft	$25.71	2	$51.42
9	808 Keychain Camera	$41.35	1	$41.35
10	Entacore AIM 3 Altimeter	$115.00	1	$115.00
11	EJECTION CANISTER CAPS - 2 PK	$3.00	1	$3.00
12	Von Karman Nose Cone, Fillament Wound Fiberglass	$48.95	1	$48.95
13	Main Body Tube, Fiberglass, 3"x48"	$78.00	1	$78.00
14	54mm (2.13 in.) Aft Body Tube, Fiberglass, 2.13" x 12"	$15.50	1	$15.50
15	Main body Coupler for 3" Fiberglass (9")	$21.00	2	$42.00
16	Firewire Initiator e-match	$2.00	15	$30.00
17	Tower hobbies 30min epoxy	$8.99	1	$8.99
18	Tower hobbies 6min epoxy	$8.99	1	$8.99
19	Arduino DUE	$49.95	1	$49.95
20	Sparkfun LIS331HH (+/- 24g)	$27.95	1	$27.95
21	Hook -Up wire	$16.95	1	$16.95
22	Adafruit 10-DOF +/- 16g IMU (L3GD20H + LSM303 + BMP180)	$29.95	1	$29.95
23	Firgelli P 16 (stroke 50mm, gear 64:1, 12V)	$90.00	1	$90.00
24	12 v tenergy battery	$26.99	1	$26.99
25	1/8" Plywood 24" x 12"	$3.99	5	$19.95
26	FOAMULAR 150 2 in. x 4 ft. x 8 ft. R-10 Scored Squared Edge Insulation Sheathing	$29.98	1	$29.98
27	Furring Strip Board (Common: 2 in. x 2 in. x 8 ft.; Actual: 1.375 in. x 1.37 in. x 96 in.)	$1.57	1	$1.57
28	1/16 in. x 3/4 in. Stainless Cotter Pin (3-Pieces)	$0.54	4	$2.16
29	Fiber Glass	$45.00	1	$45.00
30	Aluminum Plate Custom Size Length 1.5" Width 1.5" .25" Thick	$0.50	1	$0.50
31	Aluminum Round Rod Random Length	$45.02	1	$45.02
32	Plastic Natural Sheet Polypropylene .06"x12"x12"	$1.38	1	$1.38

33	Quasi-isotropic Solid Carbon Fiber Sheet 1/8x6/6 plain gloss finish	$31.30	1	$31.30
34	Competititon Cost (Including additional motors)	$444.88	1	$444.88
35	Travel Cost	$150.00	2	$300.00
				$2,617.37

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