Preliminary Design Report

Kent State University High-Power Rocket Club

Kent State University

Team Mentor: Mr. Steve Eves

Team Faculty Advisor: David B. Stringer, Ph.D.

dstring1@kent.edu 330.672.3953

Team Program Manager: Thomas Davis

tdavis81@kent.edu 440.822.5995

Team Members:

Jacob Gettens, Data Acquisition Team Leader

Maddie Wilson

Dakota Bunner

Michael Nelson

Robert Winkler, Structures Team Leader

Nelson Figuerea

Adam Fertig

Adrian Rivera

Matthew Alexander, Propulsions Team Leader

Jake Ennis

Richard Bray

Clarence Jackson

Kaushik Anantha

Tyler Bodenschatz, Safety Officer

Table of Contents

Executive Summary

The Kent State University High-Power Rocket Club is an Integrated Product Team comprised of members with varying technical majors. Our purpose is to compete in the 2016 – 2017 Space Grant Midwest High-Power Rocket Competition in support of our organizational goals:

> "To advance the arts, sciences, and technology of aeronautics and astronautics, to develop professionalism and leadership of those engaged in these pursuits, and to promote community outreach of the sciences".

Overview

This preliminary report provides:

1. Flight performance prediction methodology and models.
2. Design descriptions of our competition rocket
3. Engineering solutions to the challenges presented by this competition

Objectives

Flight performance prediction models will be completed in a manner that meets two goals:

1. To successfully meet and/or exceed, within the 2017 competition time constraints, the standards and objectives required by the competition.
2. To establish a professional approach to KSU High-Power Rocket Club competitions and events, that promotes the spirit of academia.

Design Solutions

The team's design solutions are simple yet innovative and include:

1. A non-commercial data collection package using components typically utilized in aeronautics
2. Three proposed drag system types, each of which conceived through engineering and team creativity

Competitive Advantage

Our team's competitive advantage stems from our ability to utilize many different resources and combine them to create an effective design that can meet the competition challenges. This is further reinforced by our promotion of the spirit of academia displayed in our use of fundamental equations to solve for estimated flight predictions.

Competition Rocket Description

Our rocket will be a single body rocket with single-stage motors and a two-stage landing design. The airframe will be composed of a phenolic body, fiberglass fins, and plastic cones. The removable motor housing is a phenolic body and balsa wood bulkheads with a fire-retardant wadding between the bulkhead and the engine. The motors will be housed in the same motor housing and will be using a removable case that will be large enough to contain our rocket motors and our rocket fuel. Our electronic systems will be built on balsa wood caps and stacked on top of each other throughout the rocket. Each balsa wood cap will serve as a compartmental barrier to the system to the front and to the back of each other. The landing system will be a two-stage system, one placed at the top of the first half of the body, and one placed at the top of the second half of the body. Each system will contain a charge, parachute, and drogue. The drogue will release at apogee, and the parachute will release at 700ft. however, this will need to be further analysis with practice launches.

Design

Airframe and Propulsion System

<u>Airframe</u>

The airframe design was chosen based on a weight to strength ratio (Refer to Table 3). The body is a three-inch diameter phenolic tubing. The plastic nosecone was chosen based on the weight and structural integrity. Four fiberglass fins will create little drag while keeping the rocket stable. The fins were chosen due to their light weight and swept back design. Airfoil shaped rail buttons will be used to decrease drag and increase stability. The airframe of the rocket is made to be as aerodynamic as possible.

<u>Propulsion</u>

A key parameter of this adaptability competition lies in the selection of motors. Given the choice between classes I & J motors vs. J & K motors, the latter was chosen for several reasons, which all led to the importance of the decision, based on the following assumptions:

- With a higher total impulse, the J-class motors would provide a higher altitude, on average, than that provided by the I-class motors.
- The propellant weight differential spread that was estimated was much smaller for the selection of the J & K-class motors.
- The outside diameter of the I-class motors was different from that of the J & K-class motors.
- The nozzle expansion ratio remained approximately at a 4:1 ratio when comparing the J & K-class motors, whereas the I-class motor nozzles remained at a 3:1 expansion ratio,

which ensures a smaller spread of velocity of exhaust gases at any point downstream of the throat vs. the throat velocity itself, improving overall accuracy.

- More adaptability in BATES propellant grains were more readily available in a higher-number selection of J & K-class motors than available with the I & J-class combination.

Loki J300LR

The Loki J300LR was selected due to the initial altitude of approximately 4,800 feet, allowing enough room for errors and inconsistencies, so that the key performance parameter of 4,000 feet could be obtained successfully. Additionally, the J300LR motor provided more adaptability in conjunction with most K-class motors, as it offered one of the highest choices in total impulse, but one of the lowest choices in average thrust, making an excellent candidate in maximizing both team and competition goals (*Refer to Table 1*).

Loki 527LR

The Loki 527LR was selected as the K-class motor, as it offered a much higher total thrust than the J300LR, while maintaining double its average thrust rating. The Loki 527LR was evaluated in the selection process via MATLAB coding, RockSim simulations, as well as scoring estimations given in the competition handbook, and was found to initially go above and beyond the team's key performance parameter of 4,000 feet, as well as match the altitude given by the J300LR. The 527LR also maintains a relatively low average thrust in comparison to most other K-class motors, which enables the drag system to accurately slow the rocket system to target apogee assessed by the J-class launch (*Refer to Table 2*).

Ejection Charge System

To operate and maintain the dual-deploy rocket system of the drogue and main parachutes, black powder was determined to be the substance to be ignited. This was the initial choice due to reliability, low volumetric capacity, and effectiveness from a high total impulse. It's ability to ignite slightly quicker than other forms of ejection charges also played a major factor.

The black powder will be encased in a small, cylindrically-shaped paper container, mounted by two #2 nylon shear pins, and will be triggered by an altimeter with an electric match. The number of nylon pins used will be determined by using Pascal's Law, setting the pressure inside the parachute compartments equal to the quantity of force of the explosion over the area of said compartments. This calculation shows the relation of the shear force of the pins to the affected area.

The amount of black powder to be used in the parachute compartments will be determined by applying the Ideal Gas Law, using the molar mass of the black powder itself, the universal gas constant, and the additional parameters inside the rocket, and will be set as a function of volume to the compartments themselves, which then provided the mass needed.

Recovery System

Main parachute selection was initially completed using the weight to descent velocity ratio equation as follows:

$$d = \sqrt{\frac{8mg}{\pi \rho C_D V^2}} \qquad \textbf{[Eqn. 1]}$$

Where;

$d = chute\ diameter\ [m]$
$m = rocket\ mass\ [5.44\ kg]$
$g = gravitational\ acceleration\ \left[98.2\ \frac{m}{s^2}\right]$
$\rho = density\ of\ air\ \left[estimated\ at\ 1.22\ \frac{kg}{m^3}\right]$
$C_D = drag\ coefficient\ [1.5\ for\ true\ dome\ parachutes]$
$V = descent\ velocity\ \left[\leq 7.315\ \frac{m}{s}\right]$

Equation 1 then becomes: *(for a descent rate of* $\leq 7.315\ \frac{m}{s}$ *only);*

$$d \geq \sqrt{\frac{1}{72}\frac{W}{\pi \rho C_D}}\ \text{, Where; } W = weight\ [N] \qquad \textbf{[Eqn. 2]}$$

Therefore, our selection consisted of parachutes having a minimum diameter of 1.15 meters or 45 inches.

Understanding that some parameters are estimated, our team further explored this minimum diameter using *RockSim.* If the results of *RockSim* validated our calculation, showing a calculated target descent rate of $\leq 7.315\ \frac{m}{s}\ or\ \leq 24\ \frac{ft}{s}$, we would proceed with using the smallest diameter parachute available. However, the program showed a descent rate of $\geq 7.315\ \frac{m}{s}\ or\ \geq 24\ \frac{ft}{s}$, so we adjusted the chute diameter until we obtained our target result. *RockSim* showed that a minimum diameter chute of 1.8288 meters or 72 inches was needed to acquire our target descent rate. The final verification will be completed during pre-competition launch testing.

Avionics and Data Acquisition

<u>Jolly Logic Altimeter</u>

The Jolly Logic Altimeter One can detect changes in altitude of less than one foot due to a 19-bit barometric pressure sensor. Altimeter One takes a sampling of 25 times per second, has a rugged design to survive crash landings, and stores data for the last 100 flights. This altimeter has an LCD screen, is rechargeable and displays current altitude in real-time.

The Jolly Logic Altimeter Two has an ability to provide ten key flight performance measures for each flight. These measurements include maximum altitude, top speed, the engine thrust duration, peak acceleration, ejection timing and total flight time. The team also opted for this due to approval by the National Association of Rocketry for contests. The Altimeter Two maintains a rugged design protecting it from crash landings, has a LCD screen and is able to be recharged.

This model Altimeter invested in a 3-axis accelerometer, as well as a 4X increase in processing speed.

The Jolly Logic Altimeter Three is similar to Altimeter Two except this improved altimeter is ran off of a smartphone or tablet. It collects the same data as Altimeter Two, except, all the data is recorded in the app via Bluetooth.

The team opted for the Jolly Logic Altimeter Two because it is identical to the Third except a smart device is not required to operate or store the recorded information.

StratoLoggerCF

The StratoLoggerCF can record data up to 100,000 feet MSL and records maximum altitude and velocity after the flight is completed. This altimeter has the ability for dual deployment. The deployments are programmable to desired heights or times. The computers used in the dual-deployment system are resistant to high wind speeds which could falsely trigger the system. The company, PerfectFlite claims to have tested this altimeter in 100+ MPH winds.

The option of going with this altimeter for our dual-deployment system was because of a strong recommendation by our advisor, as well as an accuracy within 0.1%.

Eagle Tree Pitot Airspeed MicroSensor V3

Due to competition regulations prohibiting the use of altimeters for airspeed measurements other methods were researched. The outcome was a Prandtl pitot-static tube, this was chosen due to its direct measurement of airspeed, much like an aircraft would do. This measurement is taken using the following equation:

$$V = (2 * \frac{\Delta p}{\rho})^{\frac{1}{2}} \qquad \textbf{[Eqn. 3]}$$

Where:

V = flow velocity

Δp = pressure differential

ρ = fluid density

However, this pitot system is only capable of measuring speeds ranging from 9 to 350 MPH and current estimations put our rocket reaching speeds of 392 MPH for the J-class motor and 648 MPH for the K-class motor. This will put the rockets operation outside of the standard operating window for the pitot system. This will need to tested in practice flights at an early enough date to search for and order a new airspeed system if required.

Eagle Tree eLogger V4

The eLogger is compatible with the MicroSensor and used in tandem to collect and log every data point. The eLogger by Eagle Tree operates at a 50Hz logging speed, and allows for the graphing of data points collected.

Toughsty Micro Camera

As per competition regulations it is necessary to record via video the launch, the burn time and when the rocket separates. The team decided to use Toughsty Micro Cameras due to their size, weight, and ability to record quality footage for a period of time.

The cameras will be bracketed to the rocket throughout the bulkhead in an attempt to obtain optimal videos. This plan will need to be tested in practice launches as well as further refined.

Uniqueness of Data Acquisition System and Avionics Bay Assembly

This system due to usage of a Prandtl pitot-static tube is unique in that it uses an aircraft based airspeed indicator and applies it to rocketry systems. This allows for a direct measurement of airspeed and follows the regulations set forth by the competition.

The Avionics Bay will be a coupler tube located between the breakaway point of the rocket. This allows for a center of balance with the rocket, as well as ease of access to the electronic components. Within the coupler each electronic component will be aligned along a board in a linear path to allow for stability and balance.

Drag System Engineering Solutions and Construction Techniques

The drag system will be assembled with the rocket during all flights but deployed only during K-motor launches. The system will be activated using an Arduino control device and triggered using time post-motor burnout or altitude. Actuation of the system will be completed by either an electronic servo-actuator or a linear-actuator. Due to the K-motor selection, we initially plan to deploy the system for the entirety of the cruise phase and stow the system just prior to apogee. Deployment time will be tested, readjusted, and validated through pre-competition launch testing. To understand how much drag will be produced by each of the following systems, the drag equation (Eqn. 3) was used and then added to our *MATLAB* code with a constant loop of velocity change. This was done in order to recalculate the drag produced at each instantaneous time within the cruise phase.

$$D = \frac{1}{2}\rho A V^2 C_D \text{ , } \textit{Where A is the area of each relative drag system} \quad \textbf{[Eqn. 4]}$$

Construction of the drag system will be completed using materials and design solutions able to withstand the forces acting on the rocket relative to the K-motor. The greatest force will be at motor burnout, which we calculated at over 15 G's. Due to these high forces, there will be a delay between motor-burnout and drag system deployment. To test the structural integrity of each drag system, static tests and wind-tunnel tests will be completed. The available wind-tunnel has a maximum speed of only 85 mph however, so final validation must be completed during pre-competition launch testing. Safety assurance dictates that redundancy within each drag system and material choice is a priority. The drag system must fully deploy in synchronous motion, or no part must deploy. This will ensure that the rocket will not tumble and will stay under our predicted stability and control.

Drag System A – Servo-Actuated Fin Tabs, Theory of Operation

Circular disks will be cut out of two fins 180 degrees apart. The disks will be reinstalled and be connected by an axis perpendicular to the rocket body at approximately one-half inch from the bottom of the disk. Upon deployment of the system, the disk will rotate 90 degrees, horizontal with the ground. The relative wind will keep the drag disks deployed. Stop brackets will be installed to support the disks against the relative wind. A torsional spring will return the disks to the vertical position prior to apogee (Refer to DWG-A).

The system provides the advantage of high strength, both in the fiberglass drag disks and the support system to help maintain structural integrity within the cruise phase. The system is also designed for minimal space, utilizing the exterior of the rocket for mounting, in lieu of the interior. Unfortunately, as each drag disk will be actuated by its own separate electronic servo-actuator, redundancy is missing and risk for single disk deployment and rocket tumbling increases.

Drag System B – Servo-Actuated Drag Tabs, Theory of Operation

This drag system will be housed in a section of phenolic coupler tubing about three inches in length. An electronic servo-actuator will drive a rotating washer perpendicularly to the rocket body. This washer will be attached to four one-inch-wide fiberglass tabs that will deploy, through slots in the rocket body, approximately one-half inch outside the main rocket body. The tabs will be connected to the drive collar via steel pins acting as rivets. Each tab will be guided using an upper and lower locking plate. The system will be located appropriately using a bulk-head mounted to the interior of the rocket body acting as a key. There will be four one-half-inch diameter brass tubes, located equidistant radially from the center of the system that will allow the motor's ejection charge to fire and the expanding gases to escape around the system. This will ensure the system is not corroded or destroyed by the gases. If one of the tabs becomes obstructed, no tab shall deploy as they are all connected to the same drive collar. The system will be attached at five separate radial points around the rocket body to the bulk heads and centering rings that make up the remaining system using rocket rivets (Refer to DWG-B).

The small area needed to mount this system is an advantage this system provides. It is also very light-weight and requires very little motion to deploy and stow the drag tabs. Space however, limits the amount of drag surface which may not allow for enough surface area to sufficiently slow the rocket to apogee. Deployment time will have to allow us to accomplish this.

Drag System C – Linear-Actuated Drag Flaps, Theory of Operation

A micro-linear-actuator will be attached to a bulk head inside a section of coupler tubing. A second bulk head will be utilized to connect the drive arm to a slider shaft that moves axially to the body of the rocket. This slider shaft will drive two drag flaps, connected at the top to the slider shaft and at the base to the main rocket body. The system will be constructed using phenolic tubing to conform properly to the rocket body and be able to stow in a streamline fashion to the rocket body. System deployment and stow are designed to be actuated by specific flight times: post motor-burnout and prior to apogee respectively (Refer to DWG-C).

The aerodynamic position created when the system is stowed is a major advantage of this system. Also, there are few moving parts creating a simple drag design. It also allows for a wide range of relative drag area, or the area that the relative wind actually encounters perpendicularly. Safety is embedded in this system as each drag flap is connected to the same drive arm and actuator. If the arm or actuator fails, it is unlikely either flap will deploy. However, the phenolic material may be unable to withstand the estimated forces acting upon the rocket, even during the cruise phase. Static and dynamic testing will confirm the actuators ability to stow the flaps. If the system shows weakness or inability to stow the flaps post-deployment, it will not be tested during actual launch. If it proves structurally sound, the test launch will be the final validation.

Risk Mitigation Analysis

Risk mitigation analysis for the rocket build took into consideration stability, control, and material choice. The design stability focused on maintaining the center-of-gravity forward of the center-of-pressure. This was validated through *RockSim* which, through flight simulation, also showed a stable rocket build. Control of the systems, including the launch and avionics systems, prove to have little risk on the flight overall. Control and redundancy within the drag systems however, show high risk on the overall stability of the rocket in flight. The redundancy and safety aspects described earlier for each of the proposed drag systems reduces the risk to the rocket and potential damage or injury to equipment or persons in the area.

Initial structural analysis of the drag systems, cameras, and pitot systems prove to have a low risk, however, launch testing will show actual stability. Upon the recovery of each pre-competition launch, the team and mentor will thoroughly inspect each of these areas in particular to ensure no damage or wear is present. If damage or wear is found, troubleshooting solutions will be realized to ensure the issue is fixed and the system is safe for further flights. The team's mentor, Mr. Steve Eves, and the team's safety officer, have reviewed the preliminary design for the rocket build, data acquisition components, and the proposed drag systems, and currently see little risk in moving forward with the planned test launches.

Predicted Performance

Performance predictions were completed using *MATLAB*. The code runs in increments of 100 samples per second updating the drag value with each iteration due to the constantly changing velocity value. Fundamental physics equations were utilized by the team to develop simple, yet sound mathematical prediction models for the *MATLAB* code. These base equations include:

$D = \frac{1}{8}\rho\pi d^2 V^2 C_D$, *Where d is the diameter of the rocket body* **[Eqn. 5]**

$F = ma$ **[Eqn. 6]**

Using Equation 6:

$a = \frac{F}{m}$ **[Eqn. 7]**

$$\frac{\Delta V}{\Delta t^2} = \frac{F}{m} \qquad \textbf{[Eqn. 8]}$$

$$V_1 - V_0 = \frac{F\Delta t^2}{m} \qquad \textbf{[Eqn. 9]}$$

$$V_1 = \frac{F\Delta t^2}{m} + V_0 \qquad \textbf{[Eqn. 10]}$$

The performance prediction models were then validated using *RockSim* (Refer to Table 4). The simulation created by this program yielded results similar, but not exact, to our predictions as the *MATLAB* code took into consideration excess drag from the cameras and pitot/static systems. The difference between the programs could be considered negligible due to this. The final validation will be the data acquired during the pre-competition test launch.

Launch Analysis

MATLAB prediction models indicate a rail departure of the rocket consisting of the J300LR to be around 47 feet per second. It predicts the rail departure of the K527LR to be around 95 feet per second. This assumes zero delay upon ignition which indicates our ability to create a delay to ensure greater stability and velocity at rail departure. Both of these are in accordance with competition thresholds and provide stability off a 10 x 10 rail according to *RockSim* validation (*Refer to Table 4*).

Flight Analysis

<u>J Motor – Loki J-300LR</u>

As per Matlab® codes the maximum acceleration is estimated to be 148 ft/s^2, the maximum velocity is 560 ft/s, the maximum altitude reached is 4050 ft, the maximum drag is roughly 18.5 pounds, and the maximum net force is approximately 54 pounds.

Another team member determined these predicted values using RockSim to verify the Matlab® solutions. The values, following the aforementioned order, are 194.49 ft/s^2, 549.46 ft/s, 4,798.97 ft, and the last two were not readily available.

As is noticed, the altitude is significantly higher from RockSim than Matlab®, and the drag force was not readily available. This is due to the lack of inclusion of a drag system in the RockSim program leading to altered values, or no values at all.

<u>K Motor – Loki K-527 LR</u>

As per Matlab® codes the maximum acceleration is estimated to be 300 ft/s^2, the maximum velocity is 980 ft/s, the maximum altitude reached is 4100 ft, the maximum drag is roughly 225 pounds, and the maximum net force is approximately 100 pounds.

Another team member determined these predicted values using RockSim to verify the Matlab® solutions. The values, following the aforementioned order, are 351.21 ft/s^2, 892.48 ft/s, 9155.95 ft, and the last two were not readily available.

Again, as is noticed, the altitude is significantly higher using RockSim than it is calculated using Matlab®, and the drag force was not readily available. This is due to the lack of inclusion of a drag system in the RockSim program leading to altered values, or no values at all.

Recovery Analysis

Drogue chute deployment will occur at apogee, while the main parachute will deploy at 700 feet AGL post-apogee. This should limit the amount of range drift caused by the drogue deployment while meeting the competition standards. The parachute will be a 72-inch diameter chute (PAR-72GD) with a drogue chute diameter of 18 inches (PAR-18R). The velocity at drogue deployment will be approximately eight feet per second and 37 feet per second for the main parachute with the J300LR motor. The velocity at drogue deployment for the K527LR motor will be approximately 14 feet per second and 32 feet per second for the main parachute. These numbers are in accordance with *RockSim*.

Stability Analysis

Stability analysis was completed through *RockSim* only. The program shows a stable flight profile for both rockets with little range drift: approximately 331 feet at landing for the J300LR and 460 feet for the K527LR (without drag system deployment). The static margin is at 1.14 according to *RockSim* for the J300LR and 1.12 for the K527LR which are both within competition thresholds. The center-of-gravity is located at 61 inches from the nose while the center-of-pressure is at 64.5 inches for both motors. This indicates stability since the center-of-gravity is located forward of the center-of-gravity. (*Refer to Table 4*)

Environmental Considerations Analysis

With respect to performance predictions, environmental analysis is considered within the *MATLAB* program. Here we can set temperature changes and therefore density changes. This will be done prior to each launch based on Meteorological Terminal Aviation Routine Weather Report (METAR) received by our safety officer. This will also help us determine the safety of flight for each scheduled launch day. For our team's performance predictions, a temperature of 70 degrees Fahrenheit.

Safety

Material-Handling Procedures

Rocket reloading kits and pyrotechnic modules to be used in competition will be stored and maintained off-site with our mentor, Mr. Steve Eves. Mr. Eves is a level three Tripoli member and will handle all rocket motors and motor-reloading kits to include transporting and loading. All instructions while at the launch pad will be given by Mr. Eves. He will also be in charge if any motor is armed yet does not fire.

Pre- and Post-Launch Procedures

As per required safety features set forth by the competition our team set up pre and post launch safety procedures. These procedures include a buddy system at all times when on the launch pad, a set amount of people around the rocket at launch, a prep team, recovery team, and a safety checklist.

When incorporating the buddy system, it is required that at a minimum two individuals inspect the rocket during launch preparation, launch and recovery. This is mandated to ensure that any mishaps are avoided, or that if a mishap occurs someone is there to aid. The mandate also ensures that more than one opinion is included to ensure maximum safety.

As per National Fire Protection Association (NFPA) 1127 code the launch team will consist of no more than five (5) noncertified Tripoli or NAR individuals not including a certified member.

There will be two teams, a preparation and recovery team. The preparation team will set the rocket up for the launch(es) minus the engine due to certification limits. The recovery team is necessary to recover the rocket once the launch has been completed.

There will also be a safety checklist that will be covered every time preparation is taking place and the launch is being set up. This will ensure that any mishaps are minimized and that everything can be cleared for launch.

Selection #1 (J-class Motor)	
Manufacturer	Loki
Designation	J300LR
Outside Diameter	0.054 m
Total Length	0.327 m
Total Impulse	1208 N-s
Average Thrust	297 N
Peak Thrust	401 N
Burn Time	4.1 s
Propellant Mass	0.62 kg
Motor Mass	1.315 kg
Propellant Type	Loki Red

Selection #2 (K-class Motor)	
Manufacturer	Loki
Designation	K527LR
Outside Diameter	0.054 m
Total Length	0.492 m
Total Impulse	1983 N-s
Average Thrust	526 N
Peak Thrust	754 N
Burn Time	3.9 s
Propellant Mass	1.015 kg
Motor Mass	1.973 kg
Propellant Type	Spitfire

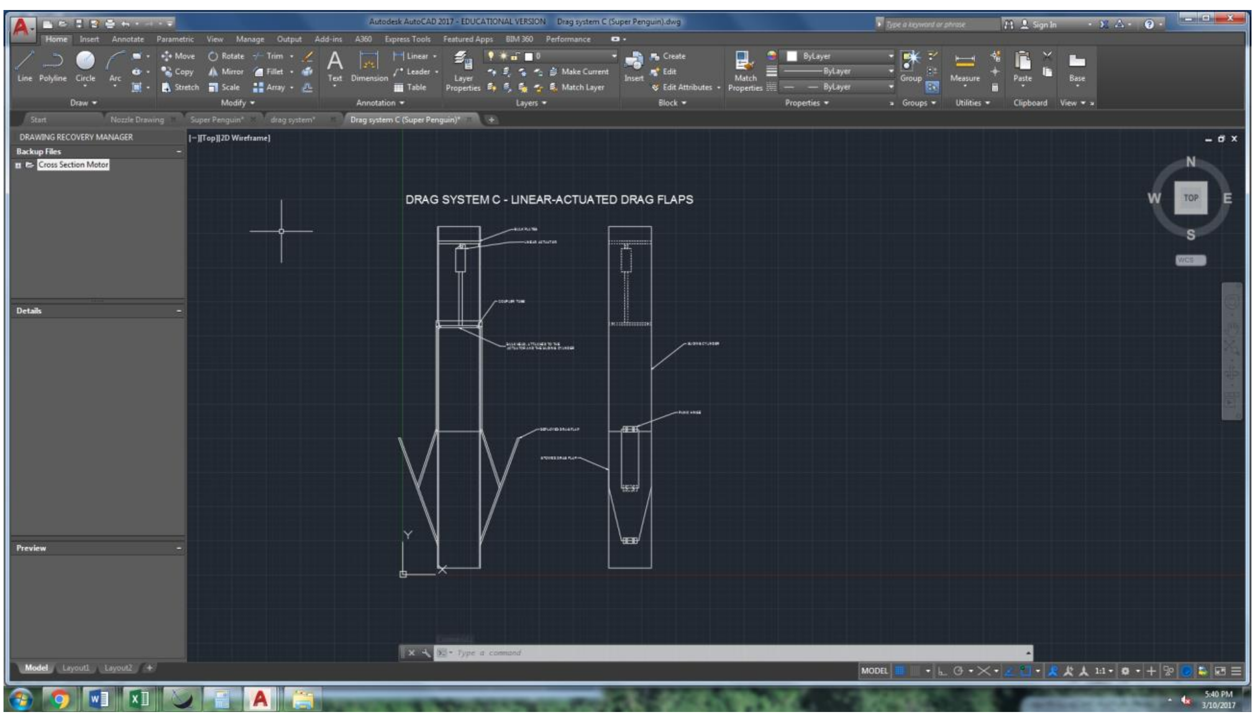
Table 1 *Table 2*

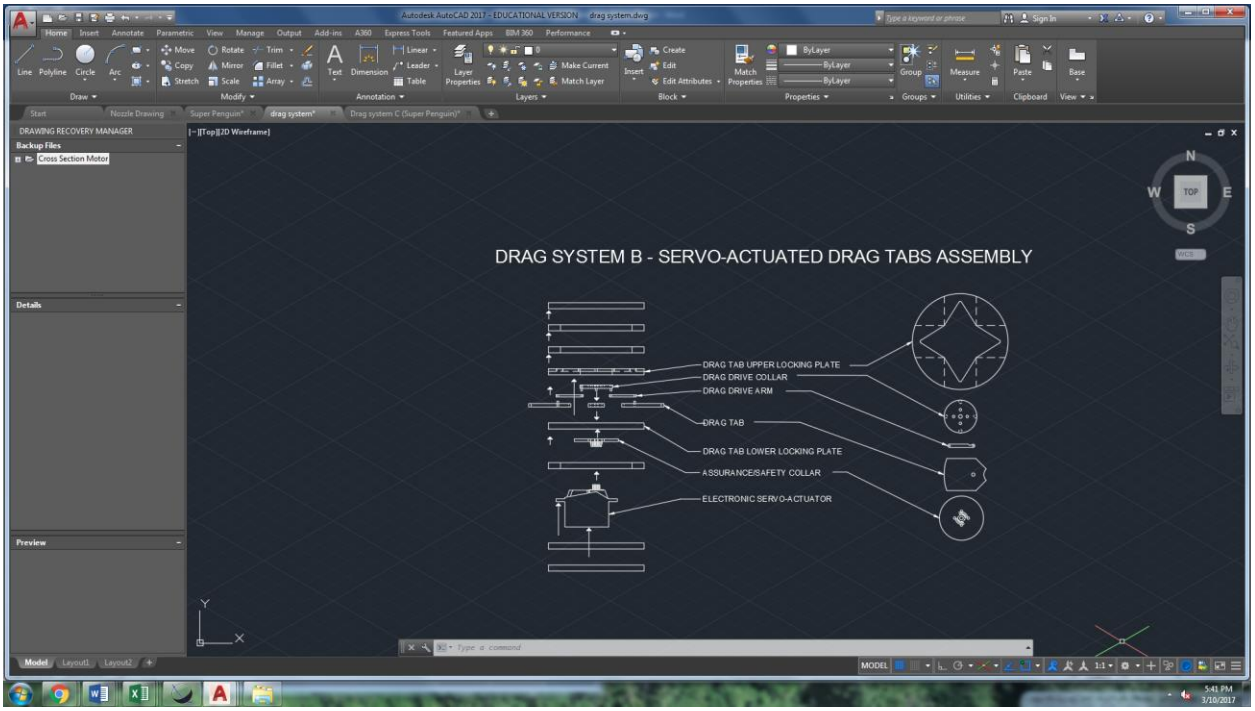
Type	Product	I.D. (in)	O.D. (in)	Wall Thickness	Length (in)	Weigth (oz)	Weight per Length (oz/in)	Price	Price per Length ($/in)	Strength
Fiberglass	3" G12 Fiberglass Filament Wound Tube 48" Long	3.00	3.14	0.07	48	34.075	0.71	$91.15	$1.90	High
Blue Tube	75mm Blue Tube	3.00	3.10	0.05	48	20.106	0.42	$29.95	$0.62	Med-High
Kraft Paper	75mm LOC MMT	3.00	3.16	0.08	34	13.827	0.41	$14.95	$0.44	Low
Kraft Paper	3.00in LOC Body Tube	3.00	3.10	0.05	34	7.972	0.23	$9.19	$0.27	Low
FGPT-3.0	Pre-Glassed Phenolic Airframe Tubing	3.00	3.19	0.10	36	23.000	0.64	$94.99	$2.64	High
PT-3.0	Phenolic Airframe Tubing	3.00	3.13	0.06	36	12.100	0.34	$18.99	$0.53	Med
QT-3.0	Quantum Airframe Tubing	3.00	3.15	0.07	36	15.200	0.42	$21.95	$0.61	Med-High
Fiberglass	4" G12 Fiberglass Filament Wound Tube 48" Long	3.89	4.08	0.09	48	47.454	0.99	$105.00	$2.19	High
Blue Tube	98mm Blue Tube	3.90	4.01	0.06	48	25.574	0.53	$38.95	$0.81	Med-High
FGPT-3.9	Pre-Glassed Phenolic Airframe Tubing	3.90	4.09	0.10	36	30.000	0.83	$104.99	$2.92	High
Kraft Paper	3.9in (98mm) LOC Body Tube	3.90	4.00	0.05	34	10.512	0.31	$11.50	$0.34	Low
PT-3.9	Phenolic Airframe Tubing	3.90	4.02	0.06	36	15.300	0.43	$20.99	$0.58	Med
PT-3.9-48	Phenolic Airframe Tubing	3.90	4.02	0.06	48	20.400	0.43	$25.99	$0.54	Med
QT-3.9	Quantum Airframe Tubing	3.90	4.03	0.07	36	18.000	0.50	$25.95	$0.72	Med-High
QT-3.9-48	Quantum Airframe Tubing	3.90	4.03	0.07	48	24.100	0.50	$32.95	$0.69	Med-High

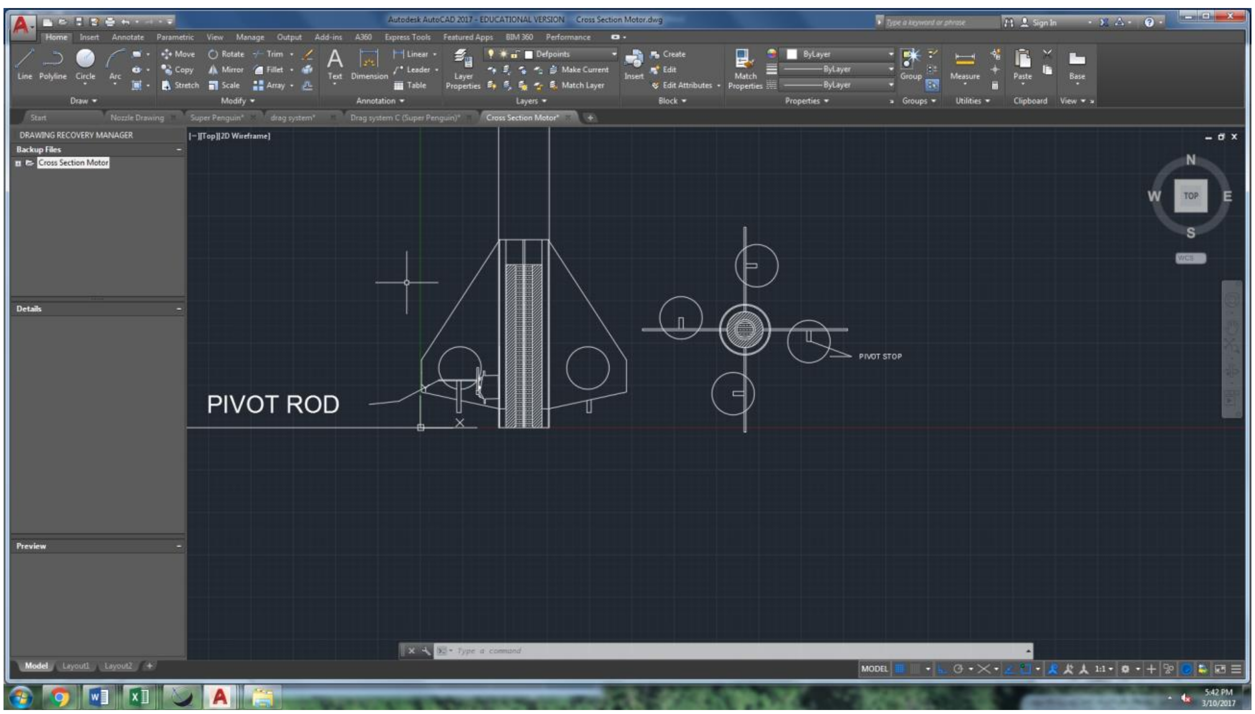
Table 3

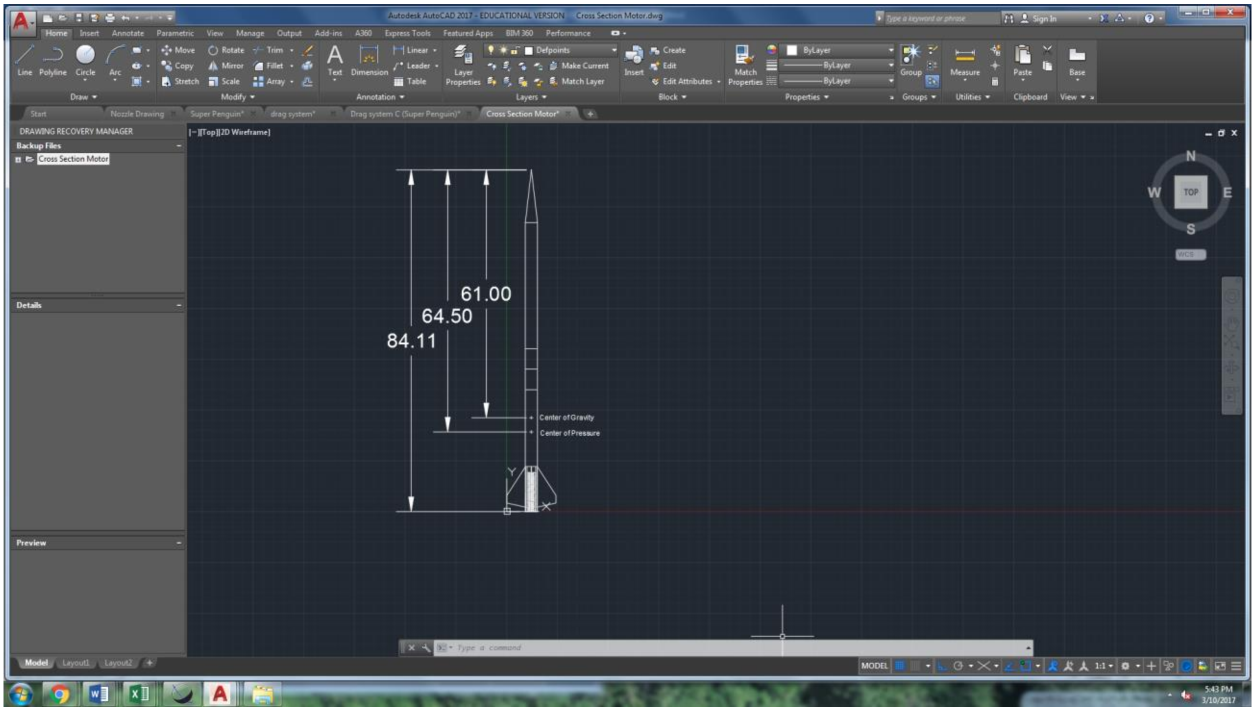
	Matlab				Rock Sim		
All Motors	Cd of rocket body, fins, cameras, pitot, servos, etc	1.500			Cd of rocket body, fins, cameras, pitot, servos, etc		
	Rocket Total Weight	53.378	N		Rocket Total Weight		N
	Rocket Diameter	1.288	m		Rocket Diameter		m
	Decending Velocity	6.691	m/s		Decending Velocity		m/s
J-Class Motors: Loki J300LR	Thrust to Weight Ratio	9.53			Thrust to Weight Ratio		
	Apogee	1,244.19	m		Apogee	1,462.73	m
	Rail Departure Velocity	14.32	m/s		Rail Departure Velocity	16.34	m/s
	Assending Velocity				Assending Velocity		
K-Class Motor: Loki K527LR	Thrust to Weight Ratio	9.53			Thrust to Weight Ratio		
	Apogee (no drag system)		m		Apogee (no drag system)	2,790.73	m
	Rail Departure Velocity		m/s		Rail Departure Velocity	21.63	m/s
	Area of Drag System A	2	in^2		Area of Drag System A	2	in^2
	Cd of Drag System A	1.5			Cd of Drag System A		
	Drag System A Deployment Delay After Motor Burnout	0.5	sec		Drag System A Deployment Delay After Motor Burnout		sec
	Area of Drag System B	19.76	in^2		Area of Drag System B		in^2
	Cd of Drag System B	1.5			Cd of Drag System B		
	Drag System A Deployment Delay After Motor Burnout				Drag System A Deployment Delay After Motor Burnout		
	Area of Drag System C	3.8	in^2		Area of Drag System C	3.8	in^2
	Cd of Drag System C	1.5			Cd of Drag System C		
	Drag System A Deployment Delay After Motor Burnout				Drag System A Deployment Delay After Motor Burnout		
	Drag System Deployment delay after motor burnout	0.5	sec		Drag System Deployment delay after motor burnout		sec
	Rail Departure Velocity				Rail Departure Velocity		
	Assending Velocity				Assending Velocity		

Table 4

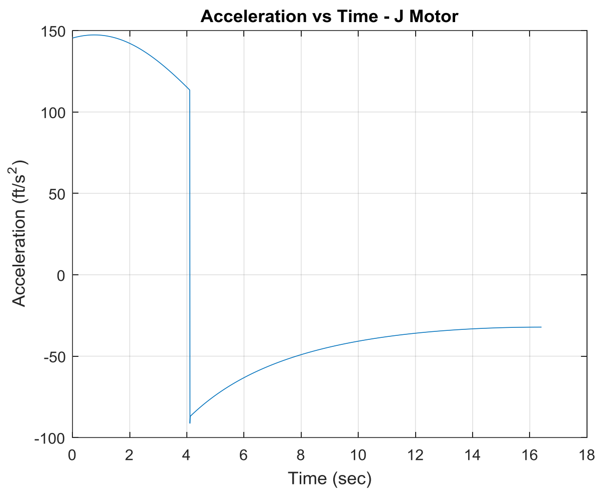

Autodesk AutoCAD 2017 - EDUCATIONAL VERSION Drag system C (Super Penguin).dwg
DRAG SYSTEM C - LINEAR-ACTUATED DRAG FLAPS

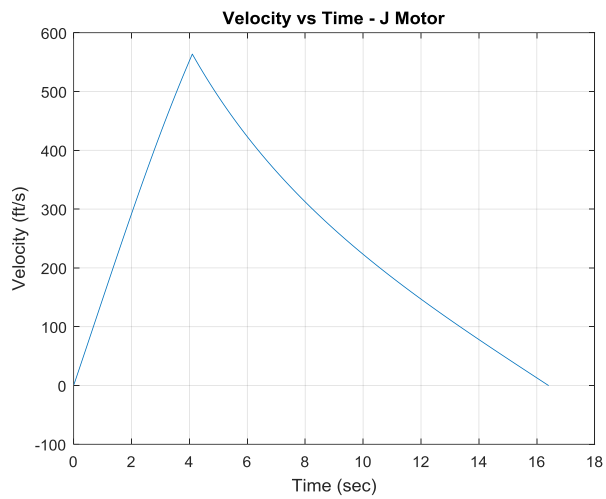

DRAG SYSTEM B - SERVO-ACTUATED DRAG TABS ASSEMBLY
DRAG TAB UPPER LOCKING PLATE
DRAG DRIVE COLLAR
DRAG DRIVE ARM
DRAG TAB
DRAG TAB LOWER LOCKING PLATE
ASSURANCE/SAFETY COLLAR
ELECTRONIC SERVO-ACTUATOR

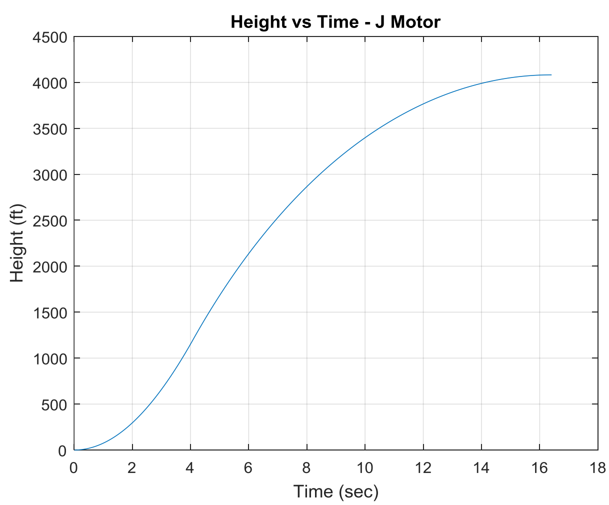

PIVOT ROD
PIVOT STOP


61.00
64.50
84.11
Center of Gravity
Center of Pressure

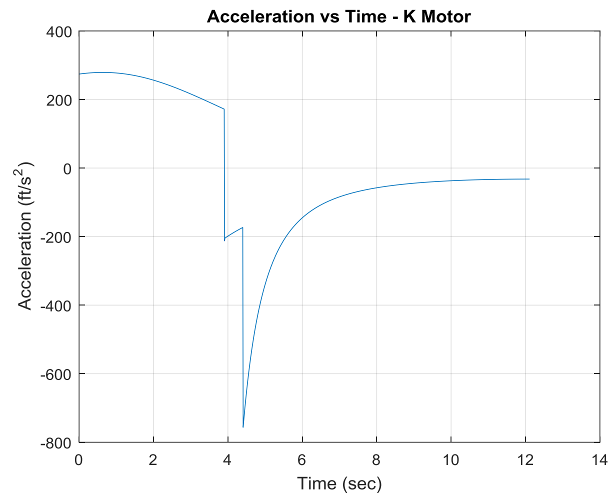
J Motor: Loki J300LR

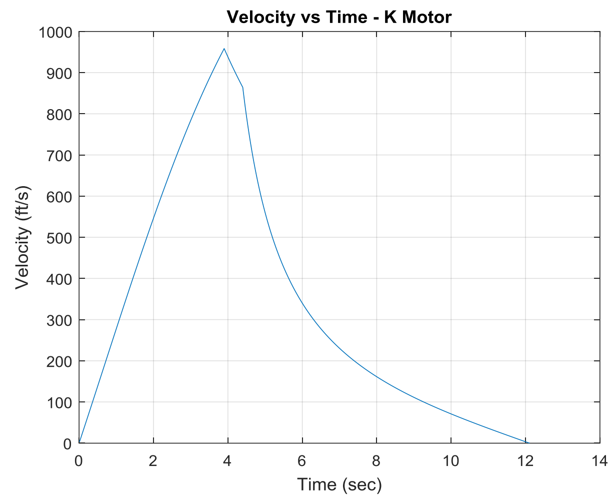


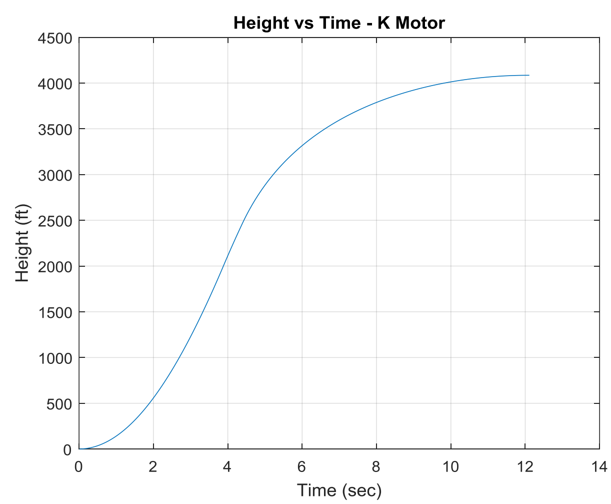




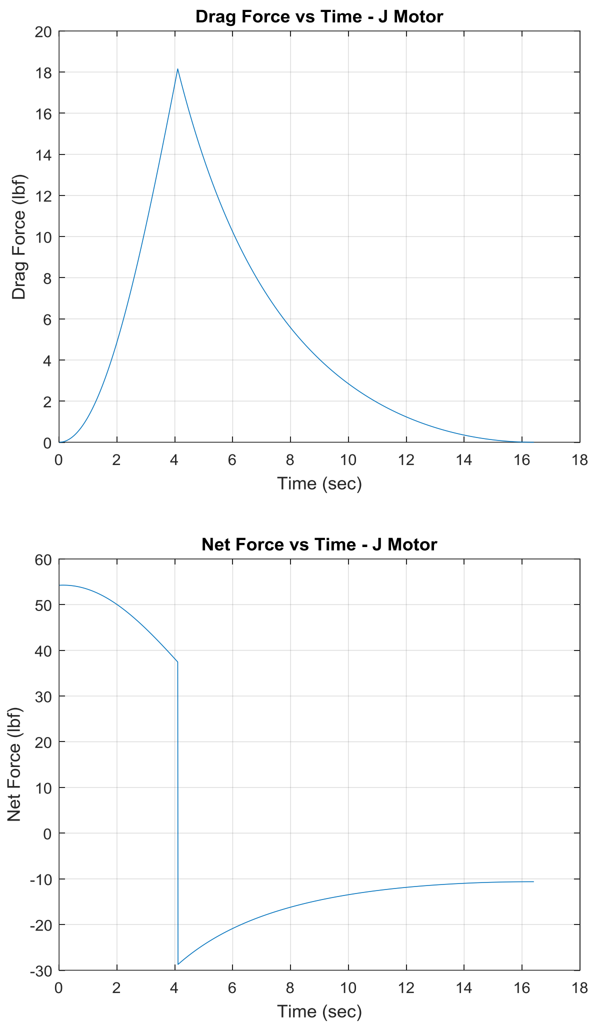
K Motor: Loki K527LR







J Motor: Loki J300LR



K Motor: Loki K527LR