University of Hawaiʻi Community Colleges

UHCC Project Imua: Mission 8

Mission 8

2019-2020

ESRA/IREC SpaceCup

imua.wcc.hawaii.edu

General Vehicle Information/Dimensions

In order to continue its efforts at promulgating interests in science, technology, engineering, and mathematics, the Center for Aerospace Education (CAE) would take the lead in construction of arre-usable rocket to perform diagnostic testing for several of our education outreach projects. The rocket would be designed to carry a non-specific payload, of limited weight and size, to a specific altitude of 9900 feet, and then be recovered safely. To ensure re-usability, the rocket would deploy a drogue chute at apogee, and a larger main chute at a lower altitude-high enough for a safe landing, yet low enough to ensure retrieval in a limited area.

(Insert diagram of rocket)

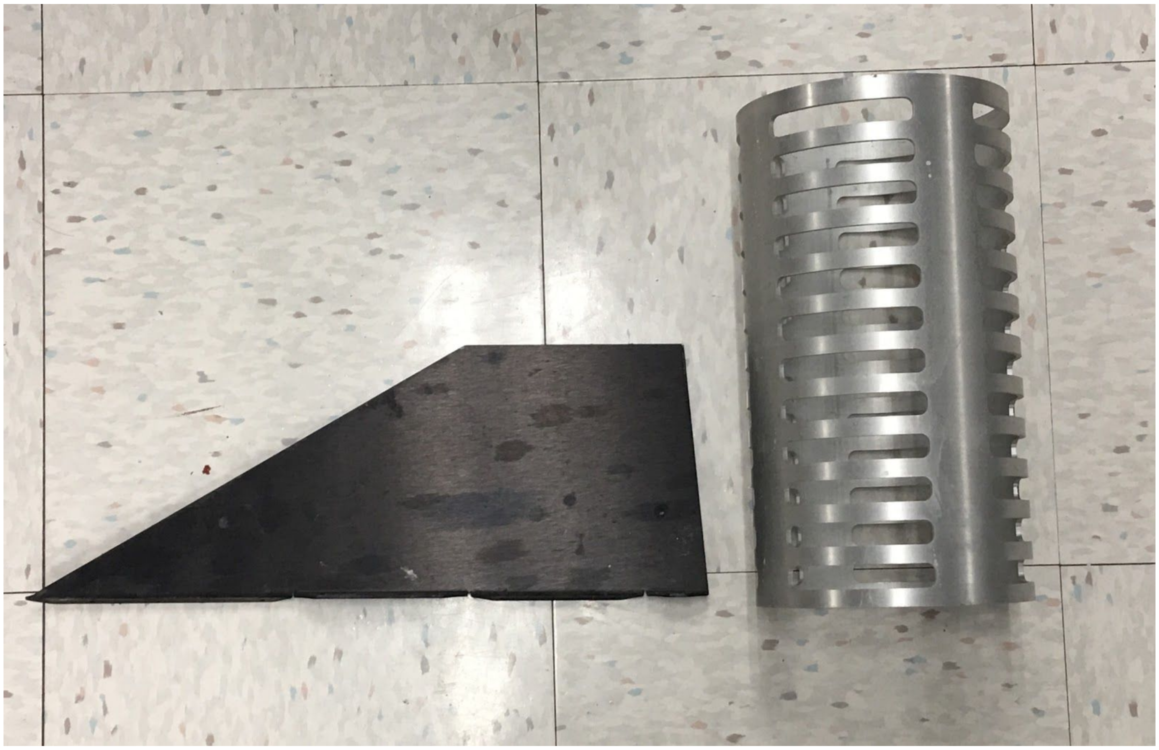
The rocket is 152 inches in length, with a 6 inch diameter. It has 4 trapezoidal fins, each having a span of 6 inches. The overall length of the rocket is determined by combining the payload needs with the logistics required by the dual deployment recovery system. The rocket design started with a choice of body diameter. This was determined by payload considerations to some extent, but mostly for chute packing considerations. A 6-inch diameter body tube was chosen because it gave the team a good flexibility in determining the payload volume, a reasonable chute packing volume, and a wide range of motors that could be used for various altitude flights. Once the diameter was set, the nosecone of standard ogive 1:5.16, yielded a nose cone length of 32 inches- which is convenient because this shape is commercially available. The nose cone will contain most of the payload electronics, and directly aft of it, the payload package itself. Attached permanently to the shoulder of the nose cone is the payload carrier section of the rocket. The length of this section was determined by estimating the length of the payload, which is 16 inches. This nosecone/tube section, referred to as the payload carrier unit, will descend separately when the main chute is deployed. The next section contains the rocket avionics, the stowed main chute, along with its deployment pyrotechnics, and the avionics container (6 inches in length). The length of this section is 48 inches, and is referred to as the Fore section. The avionics electronics will consist of an Altus Metrum TeleMega with GPS tracking and telemetry, and a perfectFlight StratologgerCF as back-up. Both of these units have been flight tested at this last ARLISS and SLP launch.

The section below the Fore section is the Booster section, which houses the motor, the motor mount, the Aero Pack quick change 98 mm Motor retainer, the fin can and 4 fins, the drogue chute, drogue deployment pyros, as well as the Variable Drag Assembly (VDA). The fin assembly is a 4-fin aluminum unit manufactured by Max Q Aerospace. The fins are machined from 0.125 inch 6006-T6 aluminum plate, and each fin is held to a can assembly using 7 hex bolts. Having fins that are removable has proven to be convenient for shipping purposes- previous SLP entries have shown that having the fins fixed made the cost of shipping exorbitant.

The rocket mass is estimated to have an unloaded weight of 24lb (10.9 kg) and a loaded, or pad weight of 47.35 lbs (21.5 kg).

(insert Rocket Fore section and Booster section)

The UHCC Team, while participating in previous SLP, ARLISS and RockSat-X attempts, has compiled a litany of ways that the postal delivery systems can damage a rocket before delivery to Los Cruces. Additionally, fins that are permanently attached to the body tube cause an exponential cost in the shipping. As such, the UHCC team has purchased from AeroPAC a CNC machined aluminum fin can made for 6' diameter body tubes. The fins are machined from 0.125' 6061-T6 Aluminum plate. The four fins are held in place by four shaped plates that are bolted through the body tube, and then into a ¼" thick aluminum internal can. Each fin has four tabs, alternating sides of the root chord, and held in place using 7 hex bolts. The final assembly is one solid integrated structure that can be disassembled for transport. The team has a great deal of experience with this assemblage, this type of assembly has been flown for the last eleven years at A Rocket Launch for International Student Satellites (ARLISS).



Fin Flutter Speed Estimate

Of interest, but not really a major concern, was of the fin flutter speed. The fin flutter speed, or the speed that yields an extraction of energy from the air stream flowing over the fins, could result in deformation of the fin while in flight. This deformation, usually a transient phenomenon, could in turn (if sustained) transform any rotational motion about a principle axis to rotation about a minor axis. In effect, fin flutter can transform rotation about the long axis into tumbling about the minor axis.

Determining the velocity of the onset of fin flutter is not hard, and was done as a NACA exercise back in 1958 [*"Summery of Flutter Experiences as a Guide to the Preliminary Design of Lifting Surfaces on Missiles"* NACA article TN4197, D. J. Martin 1958], and more recently a magazine article in Sport Rocketry [Sport Rocketry Magazine (March/April 2012 p. 18-22)];

$$\frac{v_f}{a} = \sqrt{\frac{G_E}{\left[\dfrac{39.9A^3}{\left(\dfrac{t}{c}\right)^3 (A+2)}\right]\left(\dfrac{\lambda+2}{2}\right)\left(\dfrac{P_{atm}}{P_o}\right)}} = \sqrt{\frac{G_E}{\left[\dfrac{1.337A^3 P_{atm}}{\left(\dfrac{t}{c}\right)^3 (A+2)}\right]\left(\dfrac{\lambda+2}{2}\right)}}$$

Where v_f is the flutter speed, and a is the acoustical speed in air (speed of sound). G_E is the effective shear modulus for 6061 T-6 Aluminum plate, and this can be found on-line and has a value of 28.0 GPa. The rest of the terms are based on the geometry of the fin shape. The ratio of the fin thickness to the root chord length is…

$$\frac{t}{C_R} = \frac{0.125''}{16.0''} = 0.0078$$

The Aspect Ratio A, is the ratio of the span length and the median chord length.

$$A = \frac{s}{\bar{c}} = \frac{2s}{(c_R + c_T)} = \frac{2(6.0'')}{16.0'' + 5.5''} = 0.5581$$

The tapper ratio λ, is the ratio of the tip chord length to the root chord length.

$$\lambda = \frac{5.50''}{16.0''} = 0.3438$$

Lastly, P_{atm} is the atmospheric pressure 101.3 kPa at sea level, but 0.85 kPa is used to correspond to about 3900 feet elevation, the average for Las Cruces.

$$\frac{v_f}{a} = \sqrt{\frac{20\times10^{9}\,Pa}{\left[\frac{1.337(0.5581)^{3}(0.85\times10^{3}\,Pa)}{(0.0078)^{3}(2.558)}\right]\left(\frac{2.558}{2}\right)}} = \sqrt{\frac{20.0\times10^{9}\,Pa}{(1.62\times10^{8}\,Pa)(1.279)}} = 9.8$$

So, it looks like the rocket would have to reach Mach 10 before the onset of fin flutter. Since the rocket does not ever become sonic, this is not an issue.

Determination of the Center of Gravity (CG) & Thrust-to-Weight Ratio

One of the defining points for fixed-wing rocket flight stability is that of the Center of Mass, or for sufficiently small objects (where the acceleration due to gravity over its vertical length does not change appreciably), the Center of Gravity (CG). The CG is the point where the force due to gravity is said to act on our rocket and is the weighted average distribution of the mass elements that make up the rocket. In flight, the rocket will experience external torques, which will cause rotations about the CG.

Component Part	Component Mass (*g*)	y_i = Vertical Location (*in*)	Product $m_i y_i$ (*g-in*)
Nosecone	467	14	6538
Payload	3500	22	77000
Bulkhead (fiberglass)	31	27	837
Eyebolt	32	27	864
Forward Body (48”)	1097	55	60335
AV section	463	71	33370
Chutes (payload & main)	1000	50	50000
Coupler	268	79	21172
Booster Tube (72”)	1646	115	189290
Drogue chute	800	115	92000
Fin Assembly	1850	143	264550
Motor tube	985	121	119185
Motor Retainer	110	151	16610
Motor (loaded)	10827	121	1310067
Centering ring (fore)	35	121	3255
Centering ring (mid)	35	151	3675
Centering ring (aft)	35	121	4060
	$\Sigma\, m_i = 23181\ g$		$\Sigma\, m_i y_i = 2252808\ g\text{-}in$

So;

$$y_{CG} = \frac{\sum_i m_i y_i}{\sum_i m_i} = \frac{2{,}301{,}373 g \cdot in}{24{,}064 g} = 97.18 in$$

The Center of Gravity for our rocket will be 97.2” down from the tip of the Nosecone, or 53.8” up from the bottom. For comparison, RocSim has estimated the CG being located at 100.99” from the nose tip, about a 3.9% difference. Why the difference? RocSim estimates the mass of the component parts via the use of installed data tables and estimated densities for given materials, whereas our data table was built up of actually measured values of the components. Anyway, of interest is the location of the CG should no payload be launched; the modified value of the CG location becomes 110.5” from the nose tip.

Whereas the above listing of the mass elements comprising our rocket is as complete as we can *apriori* make it, it is expected that the actual location will change due to other mass elements that we have not included (*e.g.* glue, bolts, *etc*). Because accurate location of this point is essential for our flight stability determination, and flight safety over-all, the actual location of the CG will be determined by a simple hang test just prior to the actual launches. Flight stability requires that the position of the CG be located at least two body diameters above the location of the Center of Pressure.

What directly comes out of this is that we estimate the lift-off mass of the rocket to be 23.2 kg, or a weight of 228 N ~ 51 lbs. We also estimate a burned-out mass of 20.9 kg, a weight of 206 N ~ 46 lbs. The burn-out mass consists of two units; the payload mass of 4.03 kg and the rest of the rocket, 16.9 kg. Since the chosen motor (M1575BG) for the rocket has an average thrust of 1556.4 N, and our rocket has a fully loaded weight of 228 N, the Thrust to Weight Ratio (pessimistically) is 1556N/228N = 6.8, and optimistically (using the maximum Thrust value) 2965N/228N = 13.0.

Determination of Center of Pressure (CP)

The Center of Pressure (CP) is the point on a rocket where all the external aerodynamic forces are said to act. Unlike the center of mass, which depends on mass distribution, and can change with the flight of the rocket, the center of pressure depends only on the external shape of the rocket. There are several ways to calculate this point; one could estimate its location by determining the center of area of a two-dimensional representation of the final rocket. Another way is to follow the Barrowman method, which is very similar to calculating the center of mass only instead of mass elements one considers the drag coefficients (C_N) and their effective lever arm distances (X). Because it is standard practice among rocket enthusiasts to follow the Barrowman method, this is the method we shall follow…

For our ogive nosecone:

$$(C_N)_N = 2$$
$$X_N = 0.466L_N = 0.466(31.5") = 14.679"$$

where L_N = 31.5”, is the estimated length of our nosecone.

For our four-fin rocket:

$$(C_N)_F = \left[1 + \frac{R}{R+S}\right]\left[\frac{16\left(\frac{s}{d}\right)^2}{1+\sqrt{1+\left(\frac{2L_F}{C_R+C_T}\right)^2}}\right]$$
$$= \left[1+\frac{3}{9}\right]\left[\frac{16(1)^2}{1+\sqrt{1+(0.6824)^2}}\right] = (1.33)[7.2377] = 9.6261$$

$$X_F = X_B + \frac{X_R}{3}\frac{(C_R+2C_T)}{(C_R+C_T)} + \frac{1}{6}\left[(C_R+C_T) + \frac{(C_R C_T)}{(C_R+C_T)}\right]$$
$$= 135" + \frac{5.75"}{3}\frac{(26.5)}{(21.55)} + \frac{1}{6}[(21.25" + 3.953"] = 140.27"$$

where the radius of the body (*R*) is 3.0”, the fin semi-span (*S*) is 6” with a length of the mid-chord of fin L_F of 7.75”, the body diameter (*d*) is 6”, the fin root chord (C_R) is 16”, the fin tip chord (C_T) is 5.25”, the length of the rocket from nose tip to fin root chord leading edge (X_B) is 135”, and the distance between the fin root leading edge and fin tip leading edge parallel to the body (X_R) is 5.75”.

With these four results, the distance from the nose tip to the center of pressure can now be determined;

$$X_{CP} = \frac{\sum_i (C_N)_i x_i}{\sum_i (C_N)_i} = \frac{2(14.679") = (9.626)(140.27")}{11.626} = 118.7"$$

This corresponds very closely to the CP value of 119.9” given us by RocSim, and corresponds to a distance of 32.3” from the base of the rocket.

Determining the Stability Margin

The Stability Margin is defined as the ratio of the difference between the locations of the Center of Gravity and the Center of Pressure to the rocket diameter,

$$S = \frac{|X_{CG} - X_{CP}|}{d} = \frac{|97.2" - 118.7"|}{6"} = 3.58$$

our rocket is over-stable. Whereas being over-stable is not really a stability problem, we must be aware of the surface cross-winds. An overstable rocket, due to a longer lever-arm, is prone to weather-cocking into the wind.

The question of whether our rocket is inherently stable without a payload mass being flown can also be determined, the value for the center of pressure does not change but the center of gravity has a new value of 80.5”. So,

$$S = \frac{|x_{CP} - x_{CG}|}{d} = \frac{|110" - 118"|}{6"} = 1.45$$

which is marginally stable at best. In short, this rocket cannot be launched without a payload (or an inertial equivalent) having a mass of at least 4.0 kg.

4.1.1.7 Determination of the Number of Shear pins

In order for the rocket to maintain integrity until the desired moment of separation, two sets of shear pins will be used. A first set (of 2) will keep the booster section in contact with the fore section until the time of the drogue chute deployment, and the second set (of 6) will keep the payload section attached to the fore section until the main chute and payload are deployed. For our rocket, ½”440 Teflon threaded screws will be used as shear pins for two major reasons; These have been flown numerous times for several past projects, are familiar to the team, and have worked well for us. Secondly, these are readily available to us.

In order to determine the proper number of pins, a simple stress test was performed. A bucket was attached to, and suspended below, a spare coupler unit that was held in place to a spare body tube by one of the Teflon screws acting as a shear pin. Mass was placed within the bucket until failure was reached. The total mass suspended was 20.6 kg, or 45.4 lbs. Combining this result with the cross-sectional area that the weight was distributed over the stem of the shear pin (3.2 mm X 2.4 mm), we get a stress limit of 3785 psi for a single shear pin. It should be mentioned that a literature search has listed Tensile Strength for Teflon as 3900 psi. For the rest of our calculations, we shall take a failure force 46 lbs/pin.

Once this maximum force value for a shear pin is determined, several items can then be determined. The force that the shear pins must overcome to keep the booster attached to the fore section is just the aerodynamic drag force that acts on the booster after burnout and continues till apogee. This drag force, to first order, is just the burned-out mass of the booster section, 15.8 kg or 34.7 lbs. This value is well within the failure limit of one stress pin, but two will give a redundancy that needs to be overcome by the Drogue deployment charge.

The harder value to calculate is the number of pins required to hold the payload section to the fore section while the Drogue chute is being deployed. To begin this, we need to assume a change in the speed of the forward section of the rocket as the deployment is occurring. Since the rocket (theoretically) will not be moving much at apogee, and the maximum drogue chute descent rate is chosen to 80 ft/s (~25 m/s), we can take a change in speed of 25 m/s. This change in speed corresponds to an impulse of 100 Ns, acting on the payload section (mass of 4 kg). As a conservative estimate, we assume a very short deployment time of 0.1 s (really equivalent to a sudden jerk), which yields an inertial force of 1000 N. This corresponds to an inertial force of ~225 lbs, which must be overcome by a number of shear pins. The number of shear pins needed to do this then works out to be 225 lbs/(46 lbs/pin) ~ 5. Again, we have added an extra pin for surety, and needs to be overcome by the main chute deployment charge.

Determination of the Black Powder for Pyrotechnic Charges

Determining the amount of Black Powder (BP) to deploy a chute, or separate a section of the rocket, is a delicate balancing of pushing hard enough to deploy the unit while not causing permanent damage to the rocket, or turning it into a pyrotechnic display more appropriate for the 4th of July. As it turns out, there is a semi-empirical, linear relationship between the amount of BP to be used and the product of the required ejection force (E_{eject}) and the length (L) of the section that the produced gas must expand into. The relationship is outlined by J.H. Wickman ("How to Make Amateur Rockets" 2nd Edition, section 18.5-6) and is based on several simple assumptions: the tube is instantly pressurized, no heat is lost to the rocket body tube, and the gas acts nearly ideally.

$$PV = nRT_K = m\left(22.14\frac{ft \cdot lbf}{R \cdot lbm}\right)T_R$$

where m is the mass of the gas produced (~the mass of the BP in lbs), P is the gas pressure, V is the volume the gas will occupy, and T_R is the Rankine burning temperature of BP (which is 3307 R – the Rankine scale is the Fahrenheit scale that is calibrated to Absolute zero). The expansion volume is A_{cs} L, where A_{CS} is the cross-sectional area of the gas volume, and the pressure is the ratio of the desired ejection force to the cross-sectional area (F_{eject}/A_{CS}). As such,

$$PV = \left(\frac{F_{eject}}{A_{CS}} \right) \left(A_{CS} L \right) = F_{eject} L$$

After rearranging,

$$F_{eject} L = m \left(1934.7 \frac{in \cdot lbf}{g} \right)$$

Solving for the mass, and after some experimentation, Wickman found that the addition of a 1.25 g offset was needed. The final semi-empirical relationship is…

$$m(g) = \left(5.17 \times 10^{-4} \frac{g}{in \cdot lbf} \right) F_{eject} L + 1.25g$$

The determination of the ejection force is specific to the unit being deployed and is equal to the sum of the external aerodynamic forces acting on that section rocket (which really can be set to the weight of the part of the rocket) being deployed, the force of friction between the coupler and the booster (assumed to be ~2 lbs), and the force required to overcome the number of shear pins. So, for the drogue deployment this force works out to be 23.4 lbs + 2 lbs + (2 pins)(46 lbs/pin) = 117.3 lbs. Insertion of this, along with a gas expansion length of 17", into the above expression yields a deployment charge of 2.28 g ~3g. Following the same procedure, the main chute deployment, and separation of the payload section, requires an ejection force of 8.9 lbs + 2 lbs + (6 pins)(46 lbs/pin) = 286.9 lbs. This, and an expansion length of 31", yields a deployment charge of 5.85 g ~ 6g.

Obviously, the inherent assumptions used to come up with these estimates can be questioned. Because deployment of the chutes is of utmost importance to the safety of the team, and anyone else in the vicinity, these values need to be tested. Ground testing of these charges will be performed to confirm that these values do indeed have enough force to separate the pinned units, and adequately deploy the chutes.

Determination of the Chute Sizes

The actual determination of the chutes sizes is a relatively easy process; the weight of the suspended descending unit is set equal to the drag force that the chute must supply at terminal velocity.

$$W = mg = \frac{1}{2} C_D \rho A v_T^2$$

where m is the mass of the descending unit, C_D is the drag coefficient (usually taken to be ~0.8), ρ is the density of air (1.27 kg/m^3), A is the area of the chute, v_T is the terminal velocity of the descending unit. Assuming a circular shape for our chute, and solving for the diameter (D), yields…

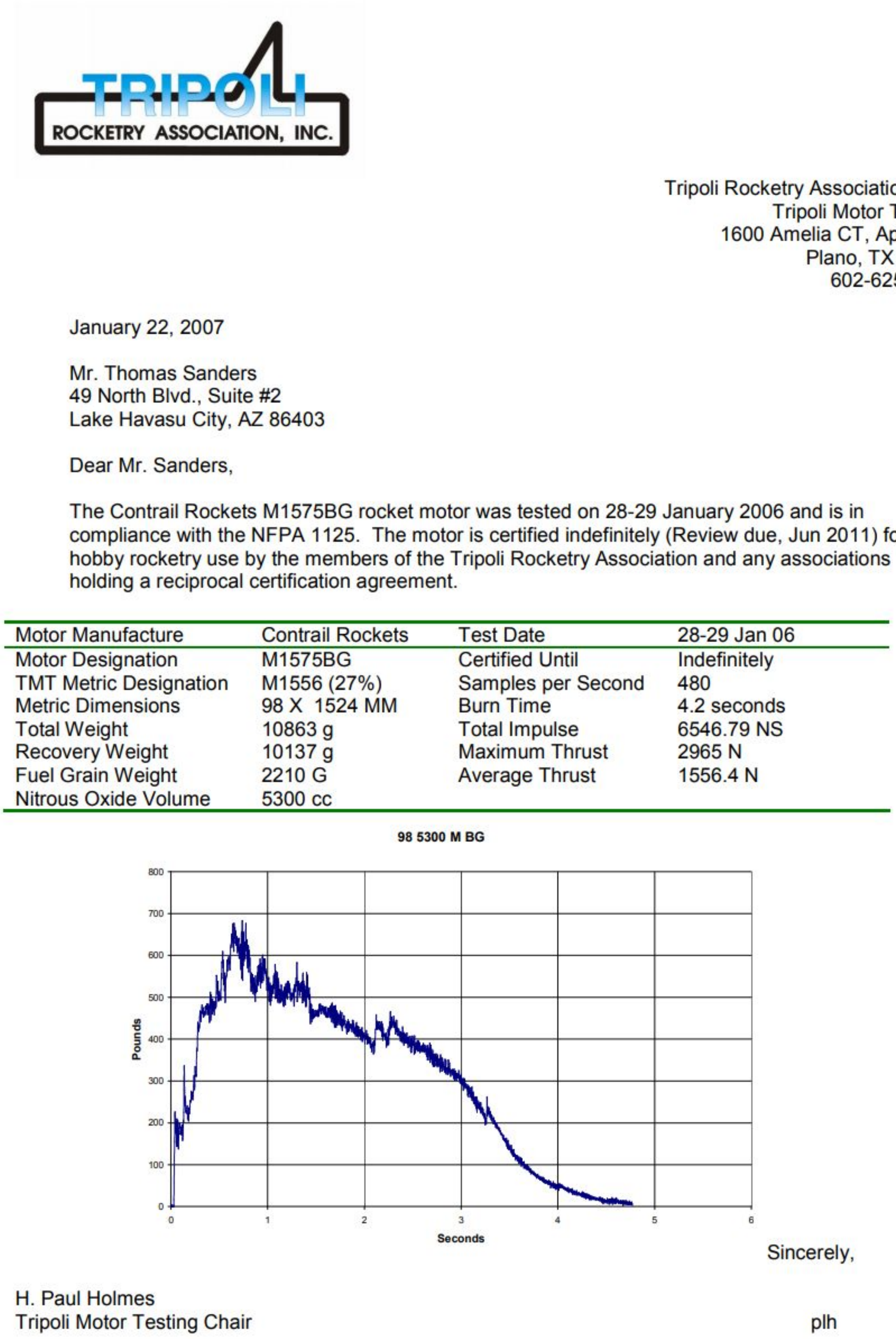
$$D = \sqrt{\frac{8g}{\pi C_D \rho}}\frac{\sqrt{m}}{v_T} = \left(4.96\frac{m^2}{s \cdot kg^{1/2}}\right)\frac{\sqrt{m}}{v_T}$$

For the drogue chute, m = 21.5 kg and v_T= 25 m/s, which yields D = 0.93 m, ~3'.

Our project will have one phase where the entire rocket will be descending at 25 m/s (~80 ft/s), and the second phase will have two units descending at 7 m/s (~25 ft/s). At 4000', the rocket will separate into the payload section, and (basically) the rest of the rocket – this will determine the main chute size. So, for the main chute, m = 17.5 kg and v_T= 7 m/s, which yields D = 2.67 m ~ 9'. For the payload section, m= 4.02 kg and v_T= 7 m/s, yields D = 1.40 m ~ 4'6".

Motor Designation and Selection

Proper motor selection requires several considerations, a suitable thrust to weight ratio, a predicted maximum altitude that is close to the desired altitude, and the physical constraints of the designed motor retention. After reviewing the preliminary design of the payload being considered, the rocket design team has decided to use a M1575BG Hybrid motor manufactured by Contrail Rockets.



Tripoli Rocketry Association, Inc.
Tripoli Motor Testing
1600 Amelia CT, Apt 1024
Plano, TX 75075
602-625-2199

January 22, 2007

Mr. Thomas Sanders
49 North Blvd., Suite #2
Lake Havasu City, AZ 86403

Dear Mr. Sanders,

The Contrail Rockets M1575BG rocket motor was tested on 28-29 January 2006 and is in compliance with the NFPA 1125. The motor is certified indefinitely (Review due, Jun 2011) for hobby rocketry use by the members of the Tripoli Rocketry Association and any associations holding a reciprocal certification agreement.

Motor Manufacture	Contrail Rockets	Test Date	28-29 Jan 06
Motor Designation	M1575BG	Certified Until	Indefinitely
TMT Metric Designation	M1556 (27%)	Samples per Second	480
Metric Dimensions	98 X 1524 MM	Burn Time	4.2 seconds
Total Weight	10863 g	Total Impulse	6546.79 NS
Recovery Weight	10137 g	Maximum Thrust	2965 N
Fuel Grain Weight	2210 G	Average Thrust	1556.4 N
Nitrous Oxide Volume	5300 cc		

98 5300 M BG

Sincerely,

H. Paul Holmes
Tripoli Motor Testing Chair

plh

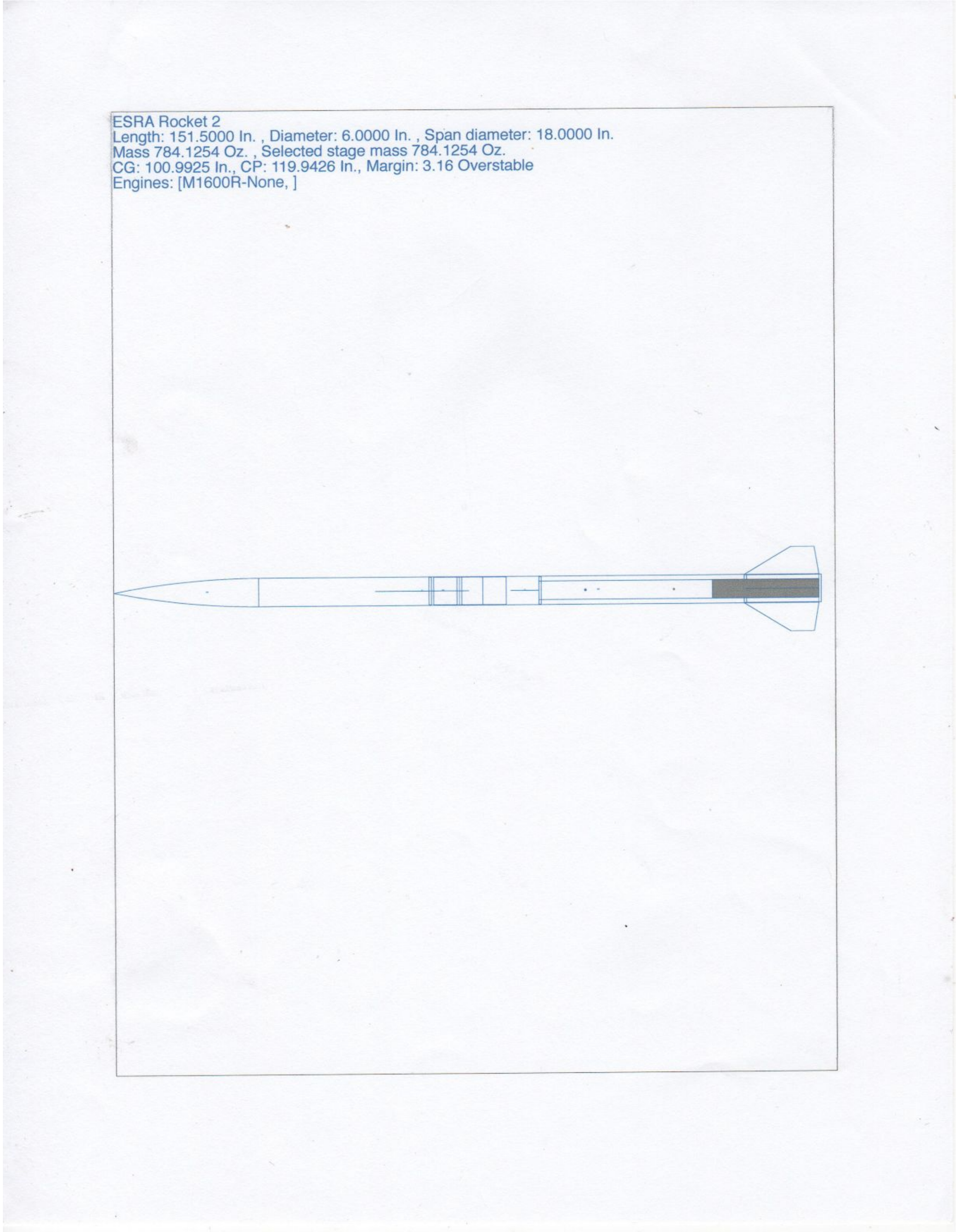
In the absence of air resistance, the maximum height a rocket will ascend to under a vertical launch situation is given by summing the height at motor burn-out and the height the rocket will coast to thereafter. As it turns out, a height determination can be found from knowing the mass of the rocket and the mass of the un-burned motor and then burned motor. If M_o is the initial lift-off mass of rocket, M is the mass of the rocket at burn-out, and $\dot{M} = (M_o - M)/t_{bo}$ is how quickly the motor is ejecting mass at an assumed constant speed of v_{ex}.

$$h=\left\{v_{ex}\frac{M_o}{\dot{M}}\left[1-\frac{M}{M_o}\left(\ln\frac{M_o}{M}+1\right)\right]-\frac{g}{2}\left(\frac{M_o}{\dot{M}}\right)^2\left(1-\ln\frac{M}{M_o}\right)^2\right\}+\left\{\frac{1}{2g}\left[v_{ex}\ln\frac{M_o}{M}-g\frac{M_o}{\dot{M}}\left(1-\frac{M}{M_o}\right)\right]^2\right\}$$

Whereas this method appears to give us all the information that we would require to make a proper motor selection, it does however neglect air friction, which we have found to be especially significant. To get a sense of how much air friction plays a part, using flight data from our last ARLISS flight of this rocket, a theoretical height determination using the above relation can be made. At a previous ARLISS (A Rocket Launch for Student Satellites) event, a prototype rocket (using a K1050W) had a pad mass of 12.40 kg, a propellant mass of 1.261 kg, a motor burn time of just over 2 seconds, and a given impulse of 2451 Ns. These values combine to yield a mass-loss rate of 0.63 kg/s, and average thrust of ($\bar{F} = I/t$) 1225.5 N, and an exhaust velocity ($v_{ex} = \bar{F}/\dot{M}$) of 1945.2 m/s. Insertion of these values into the above yields an estimated altitude for the rocket of 2988 meters. The actual height was 1,770 m; roughly only 59% of the estimated height.

A much more realistic way to establish a height determination, one incorporating air resistance, would be to deal with discrete time elements, determining the motor mass loss, the average acceleration for that time interval, the instantaneous velocity at the end of that time interval, and the drag force at the end of the time interval. These values are then used to determine the next time intervals' average acceleration, and the whole process is iterated until a maximum height (corresponding to a zero vertical velocity) is reached. This is what OpenRocket and RocSim does for us – in a very much quicker manner then done by hand, we might add!

Our challenge is that we could not find any hybrid motor selections for the internal RocSim data-base for its program. As such, we did come up with an estimate for our rocket performance: We simulated the flight using an Aerotech M1600R which had a very similar thrust profile and burn time. However, the M1600 motor has an overall mass of 6.717 kg and an overall length of 23.6", whereas the M1575BG has an overall mass of 10.863 kg and a length of 60". In order to obtain viable results from the simulation, a mass element (5.146 kg) was placed 35.2" from the bottom of the rocket – this served to emulate the mass of the hybrid motor while preserving the location of where the center of mass for the hybrid motor would be located. With these changes in place, RocSim estimates a maximum height of 9730', a maximum speed of 908 ft/s (~0.8 M), max acceleration of 254 ft/s^2 (~8 G), and a time to apogee of ~24 s.



ESRA Rocket 2
Length: 151.5000 In. , Diameter: 6.0000 In. , Span diameter: 18.0000 In.
Mass 784.1254 Oz. , Selected stage mass 784.1254 Oz.
CG: 100.9925 In., CP: 119.9426 In., Margin: 3.16 Overstable
Engines: [M1600R-None,]

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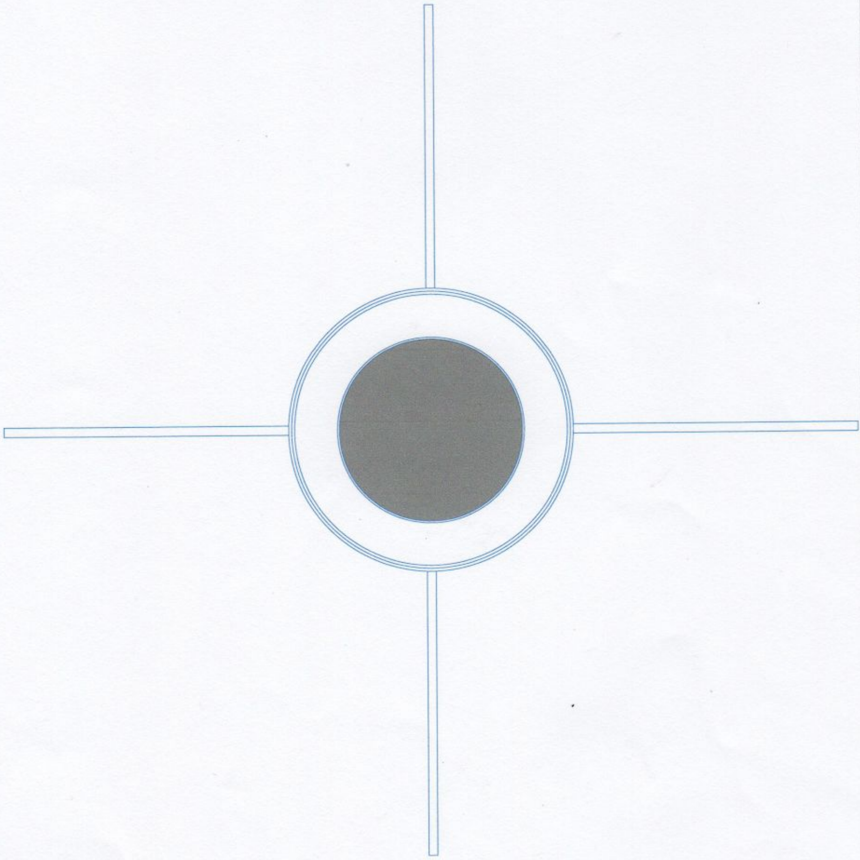

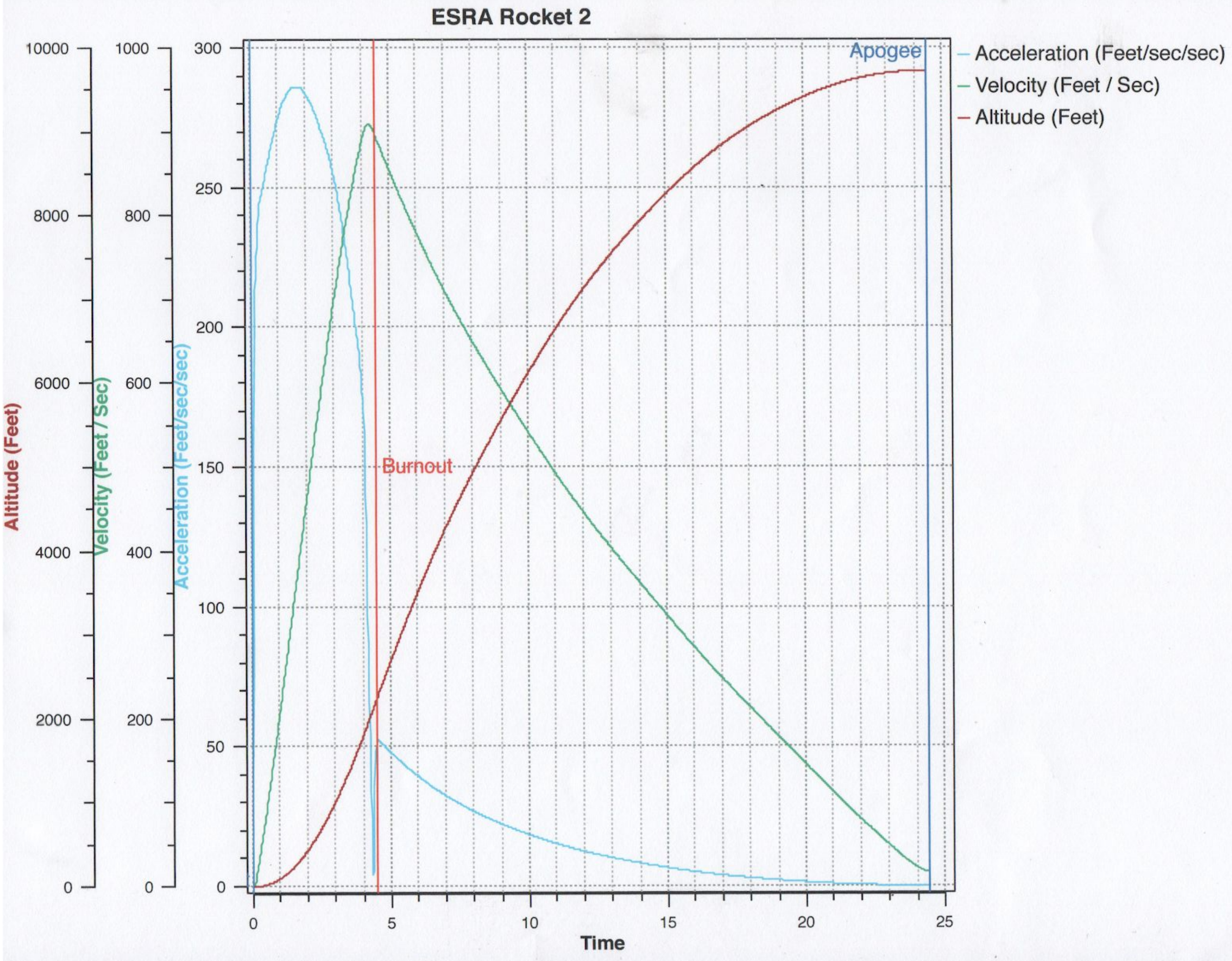
ESRA Rocket 2
Altitude (Feet)
10000
8000
6000
4000
2000
0
Velocity (Feet / Sec)
1000
800
600
400
200
0
Acceleration (Feet/sec/sec)
300
250
200
150
100
50
0
Burnout
Apogee
0
5
10
15
20
25
Time
Acceleration (Feet/sec/sec)
Velocity (Feet / Sec)
Altitude (Feet)

Sustainer parts

Nose cone - Custom, Material: Fiberglass

- Nose shape: Hollow Ogive, Len: 31.0000 In., Dia: 6.0000 In. Wall thickness: 0.1250 In. Body insert: OD: 0.0000 In., Len: 0.0000 In.
- CG: 19.4720 In. , Mass: 3.5192 Oz. Radius of gyration: 0.280373 (m) , 28.0373 (cm) Moment of inertia: 0.00784274 (kgm^2) , 78427.4 (gcm^2) , RockSim XN: 14.4225 In. , CNa: 2

Payload Object - Custom, Material: Custom

-
- CG: 0.0000 In. , Mass: 123.4589 Oz. Radius of gyration: 0 (m) , 0 (cm) Moment of inertia: 0 (kgm^2) , 0 (gcm^2)

Forward Section - Custom, Material: G10 fiberglass

- OD: 6.0000 In. , ID: 5.8750 In. , Len: 48.0000 In.
- CG: 24.0000 In. , Mass: 61.6282 Oz. Radius of gyration: 0.35637 (m) , 35.637 (cm) Moment of inertia: 0.221885 (kgm^2) , 2.21885e+06 (gcm^2) , RockSim XN: 0.0000 In. , CNa: 0

Tube coupler - Custom, Material: Fiberglass

- Tube couplerOD: 5.8750 In., Hole #1: : 146.0500 In. Len: 10.0000 In. Location: 43.0000 In. From the front of Forward Section
- CG: 5.0000 In. , Mass: 0.8454 Oz. Radius of gyration: 0.0901082 (m) , 9.01082 (cm) Moment of inertia: 0.000194596 (kgm^2) , 1945.96 (gcm^2)

AV Aft Bulkhead - Custom, Material: Birch

- BulkheadOD: 5.8750 In., Len: 0.5000 In. Location: 42.5000 In. From the front of Forward Section
- CG: 0.2500 In. , Mass: 5.3339 Oz. Radius of gyration: 0.0375281 (m) , 3.75281 (cm) Moment of inertia: 0.000212961 (kgm^2) , 2129.61 (gcm^2)

AV Fore Bulkhead - Custom, Material: Birch

- BulkheadOD: 5.8750 In., Len: 0.5000 In. Location: 36.5000 In. From the front of Forward Section
- CG: 0.2500 In. , Mass: 5.3339 Oz. Radius of gyration: 0.0375281 (m) , 3.75281 (cm) Moment of inertia: 0.000212961 (kgm^2) , 2129.61 (gcm^2)

Tube coupler - Custom, Material: Fiberglass

- Tube couplerOD: 5.8750 In., Hole #1: : 146.0500 In. Len: 6.0000 In. Location: 37.5000 In. From the front of Forward Section
- CG: 3.0000 In. , Mass: 0.5072 Oz. Radius of gyration: 0.0683439 (m) , 6.83439 (cm) Moment of inertia: 6.71672e-05 (kgm^2) , 671.672 (gcm^2)

AV Electronics - Custom, Material: Custom

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- CG: 0.0000 In. , Mass: 14.1096 Oz. Radius of gyration: 0 (m) , 0 (cm) Moment of inertia: 0 (kgm^2) , 0 (gcm^2)

Main Parachute LOC Precision - - , Material: Rip stop nylon

- 1 parachute, Shape: Round Dia: 120.0000 In., Spill hole: 0.0000 In.
- CG: 10.0000 In. , Mass: 17.2058 Oz. Radius of gyration: 0.149822 (m) , 14.9822 (cm) Moment of inertia: 0.0109489 (kgm^2) , 109489 (gcm^2)

Booster - Custom, Material: G10 fiberglass

- OD: 6.0000 In. , ID: 5.8750 In. , Len: 72.0000 In.
- CG: 36.0000 In. , Mass: 92.4424 Oz. Radius of gyration: 0.531212 (m) , 53.1212 (cm) Moment of inertia: 0.739525 (kgm^2) , 7.39525e+06 (gcm^2) , RockSim XN: 0.0000 In. , CNa: 0

Fin Can - Custom, Material: Fiberglass

- Tube couplerOD: 5.8750 In., Hole #1: : 146.0500 In. Len: 16.0000 In. Location: 56.0000 In. From the front of Booster
- CG: 8.0000 In. , Mass: 1.3526 Oz. Radius of gyration: 0.128551 (m) , 12.8551 (cm) Moment of inertia: 0.000633694 (kgm^2) , 6336.94 (gcm^2)

Centering ring - Custom, Material: Basswood

- Centering ringOD: 5.8750 In., ID: 3.9370 In., Len: 0.5000 In. Location: 72.0000 In. From the front of Booster
- CG: 0.2500 In. , Mass: 3.3258 Oz. Radius of gyration: 0.0451084 (m) , 4.51084 (cm) Moment of inertia: 0.000101848 (kgm^2) , 1018.48 (gcm^2)

0.000191848 (kgm^2) , 1918.48 (gcm^2)

Centering ring - Custom, Material: Basswood

- Centering ringOD: 5.8750 In., ID: 3.9370 In., Len: 0.5000 In. Location: 56.0000 In. From the front of Booster
- CG: 0.2500 In. , Mass: 3.3258 Oz. Radius of gyration: 0.0451084 (m) , 4.51084 (cm) Moment of inertia: 0.000191848 (kgm^2) , 1918.48 (gcm^2)

Centering ring - Custom, Material: Basswood

- Centering ringOD: 5.8750 In., ID: 3.9370 In., Len: 0.5000 In. Location: 12.0000 In. From the front of Booster
- CG: 0.2500 In. , Mass: 3.3258 Oz. Radius of gyration: 0.0451084 (m) , 4.51084 (cm) Moment of inertia: 0.000191848 (kgm^2) , 1918.48 (gcm^2)

Motor Mount - Custom, Material: Fiberglass

- OD: 3.9370 In. , ID: 3.8583 In. , Len: 60.0000 In. Location: 12.0000 In. From the front of Booster
- CG: 30.0000 In. , Mass: 2.1426 Oz. Radius of gyration: 0.441828 (m) , 44.1828 (cm) Moment of inertia: 0.0118574 (kgm^2) , 118574 (gcm^2)

Fin set - Custom, Material: G10 (PML 0.125)

- Planform: trapezoidal, Root chord: 16.0000 In., Tip chord: 5.0000 In., Semi-span: 6.0000 In., Sweep: 10.0000 In., Mid-Chord: 7.5000 In. Misc: Location: 56.0000 In. From the front of Booster Thickness: 0.1875 In. Profile: square
- CG: 143.0000 In. , Mass: 65.0000 Oz. Radius of gyration: 0.101496 (m) , 10.1496 (cm) Moment of inertia: 0.0189825 (kgm^2) , 189825 (gcm^2) , RockSim XN: 141.9921 In. , CNa: 13.0664

Drogue LOC Precision - - , Material: Rip stop nylon

- 1 parachute, Shape: Round Dia: 36.0000 In., Spill hole: 0.0000 In.
- CG: 3.0000 In. , Mass: 1.5485 Oz. Radius of gyration: 0.0532219 (m) , 5.32219 (cm) Moment of inertia: 0.00012435 (kgm^2) , 1243.5 (gcm^2)

Hybrid Overmass - Custom, Material: Custom

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- CG: 0.0000 In. , Mass: 181.6609 Oz. Radius of gyration: 0 (m) , 0 (cm) Moment of inertia: 0 (kgm^2) , 0 (gcm^2)