NASA Student Launch ARW Rocketry by the Numbers

PRESENTED BY NASA Student Launch

DATE July 24, 2023

NASA STEM

Parachute Selection

Kinetic Energy (KE):

Energy of motion

Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing. There are many forms of KE

Focus on translational motion –motion linearly from point A to point B.

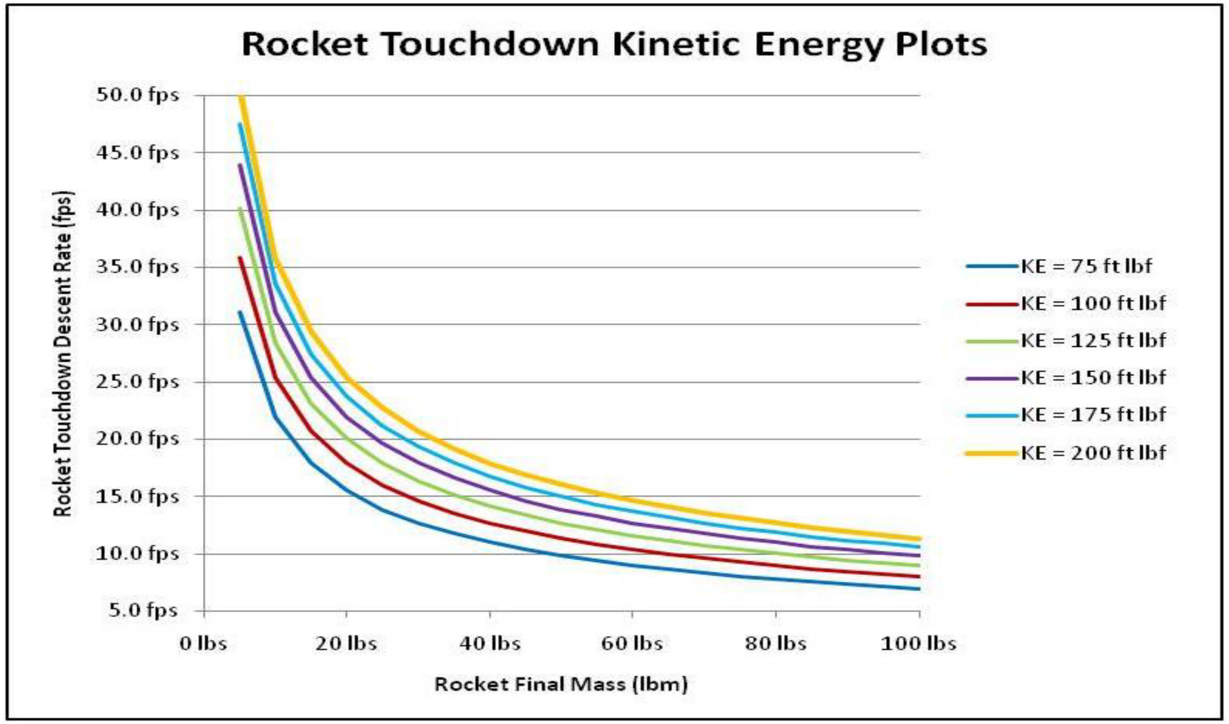
KE is a scalar quantity

Typical units:

- foot-pounds force (ft-lbf) [English]
- Joules (J = Nm) [SI]

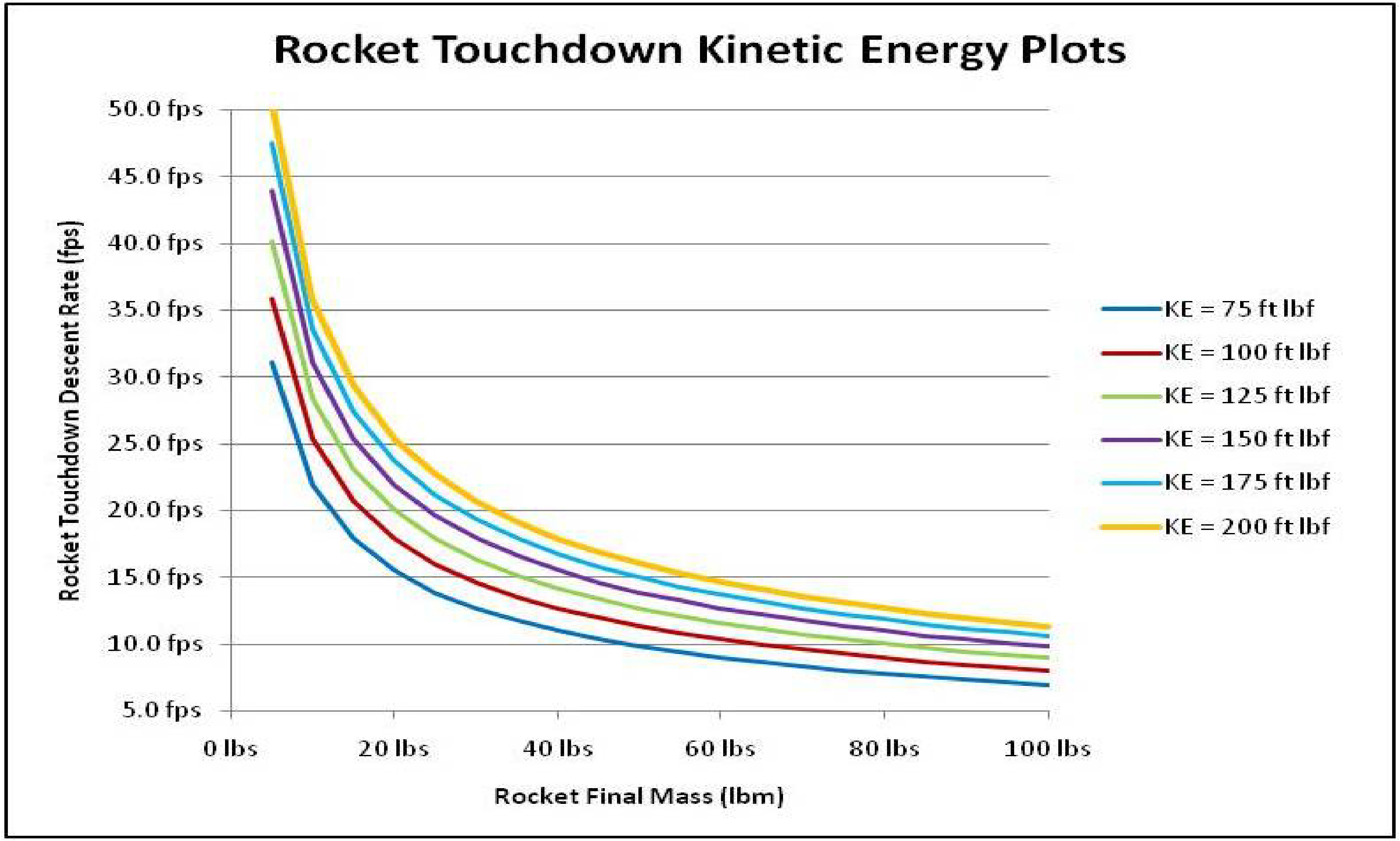
The KE of an object is dependent upon two variables:

- Mass (m)
- Speed (V)



$$KE = \frac{1}{2}mv^2$$

Parachute Selection



Launch vehicle with 3
Independent tethered sections

Parachute Selection

Recall that drag is determined by:

$$D = {}^{1}\!/_{2}\,\rho V^2 S C_d$$

- Velocity
- Air density
- Reference area
- drag coefficient (c_d)

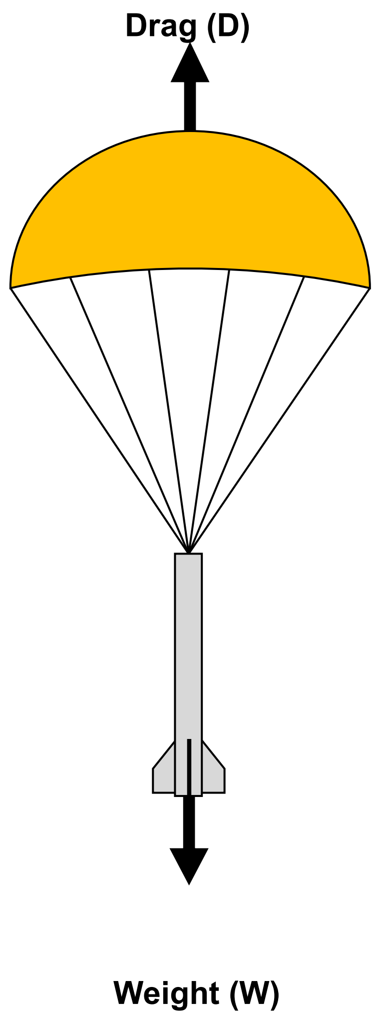
Substituting the drag equation, Newton's 2nd Law becomes:

$$W = D = {}^{1}\!/_{2}\,\rho V^2 S C_d$$

The equation is reordered to solve for the reference area (S):

$$S = {}^{2W}\!/_{\rho V^2 C_d}$$

Make an initial guess for the rocket's weight and set your drag coefficient to numbers varying from 0.8 to 2.5 and solve for reference area (S). This will help you begin to determine a range to shop for parachutes.



Parachute Selection

Perform the calculations again using the specific parachutes reference area and the manufacturer's calculated drag coefficient

(Descent Velocity = 18 ft/s) typically want below 20 ft/s for your landing velocity

$$S = {2W}/{\rho V^2 C_d} = \frac{2 * 20lbm}{0.075 \, {lbf}/{ft^3} * 18 \, {ft}/{s} * 2.0}\left(\frac{32.2\ lbm}{lbf \cdot s^2/ft}\right) = 26.5ft^2$$

For this case, the rocket will require a parachute that has an area of 26 ft^2

Your design will continue to mature, and you will need to re-evaluate your parachute selection as you get better estimates for your rocket's weight

….and now some simpler methods

Parachute Selection

Manufacturer Data

STANDARD 'CHUTES	X-TYPE 'CHUTES
9" 1-2 OZ.	10" 2-3 OZ.
12" 2-3 OZ.	18" 4-12 OZ.
15" 3-5 OZ.	24" .75-1 LB.
18" .5-1 LB.	30" 1-1.75 LB.
24" 1-1.75 LB.	36" 1.5-2.5 LB.
30" 1.75-3 LB.	42" 2.5-3.5 LB.
36" 3-5 LB.	48" 3.5-4.5 LB.
45" 5-7 LB.	54" 4.5-5.5 LB.
50" 7-9 LB.	60" 5.5-7.5 LB.
58" 9-12 LB.	70" 7.5-9.5 LB.
72" 12-18 LB.	80" 9.5-12.5 LB.
84" 18-24 LB.	90" 12.5-17.5 LB.
96" 20-32 LB.	
120" 32-50 LB.	

Parachute Selection

SkyAngle™ Parachutes	Cd	feet/sec. 17	20	25
Classic/Classic II 20	0.80	0.7	1.0	1.5
Classic/Classic II 24	1.16	1.0	1.4	2.2
Classic/Classic II 28	0.93	1.5	2.0	3.2
Classic/Classic II 32	1.14	2.1	2.8	4.4
Classic/Classic II 36	1.34	2.7	3.7	5.7
Classic/Classic II 44	1.87	4.4	6.1	9.5
Classic/Classic II 52	1.46	6.8	9.5	14.8
Classic/Classic II 60	1.89	10.2	14.2	22.1
CERT-3™ Drogue	1.16	1.0	1.4	2.2
CERT-3 Large	1.26	16.2	22.4	35.0
CERT-3 Xlarge	2.59	32.6	45.2	70.6
CERT3 XXLarge	2.92	60.0	83.1	129.8
weight load (lbs.) for given descent rate (@ sea level)				

Do not assume drag coefficient ratings are accurate on vendor websites

Parachute Selection

FRUITY CHUTES
Professional Aerospace Recovery Solutions

Home | Webstore | Parachute Recovery Systems | Drone and UAV Parachutes | Help and Recources |

Home >> Help for Parachute and Fruity Chutes Products >> Parachute Descent Rate Calculator

Parachute Descent Rate Calculator

This tool will plot the descent rate of two parachutes around the weight you specify. To use the tool:

- Enter the parachute model you want to plot. The primary chute goes on the left side. The optional chute to compare with goes on the right. Leave this blank if you do not want a second chute plotted. The form fields with the chute's diameter and Cd (coefficent of drag).
- You can override the diameter or the Cd to test how a different chute would perform or how Cd affects performance.
- Enter the target weight. The default is 11 lbs (5Kg). The plot will then graph the parachute performance based on weight.
- Hit return to update the plot after you override values. Or press "Update" after changing any values.
- Compare our chutes alongside the products of other manufactureres.

*** IMPORTANT NOTE ABOUT REFERENCE DIAMETER**: Reference Diameter is used to calculate the descent velocity drag area. For Fruity Chutes parachutes, this diameter is the same as the opening diameter of the chute. Th parachute is calculated as Pi * D / 4, where D is the reference diameter. For flat sheet chutes like Top Flight, the reference diameter is the flattened diameter of the chute - again the diameter quoted by the manufacturer. Fo manufacturers, the chute's size is measured by the distance (circumference) across the canopy. Or in some cases it's just a model number and we are not sure of the exact size. This includes Rocket Man, Spherachute, Sky Ar TAC chutes. For these the equivalent reference diameter is calculated based on the geometry of the canopy while in flight. This then becomes the reference diameter used to calculate the descent velocity. For these chutes y the diameter is different from the size of the manufacturer. For example, a Spherachute 120" parachute has an equivalent diameter if 76.4 inches. However, the Cd of the Spherachute parachute is set to 1.5 so the resulting the manufacturers data. For these chutes the Cd is adjusted so the resulting descent rate matches the manufacturer's published rates for that model. This has occasionally caused some confusion for people using the calcul manufacturers' chutes.

Manufacturer: Fruity Chutes

Manufacturer: select manufacturer to compare (click here)

[Parachute Descent Calculator]

Manufacturer:

Fruity Chutes

Model:

IFC-60-S - 60 in Iris Ultra Compact with Spectra lines

Reference Diameter (in)*:

60.0000

Cd (Projected):

2.20

Target Weight (lbs):

11

Manufacturer:

select manufacturer to compare (click here)

Compare Model:

select parachute to compare (click here)

Reference Diameter (in)*:

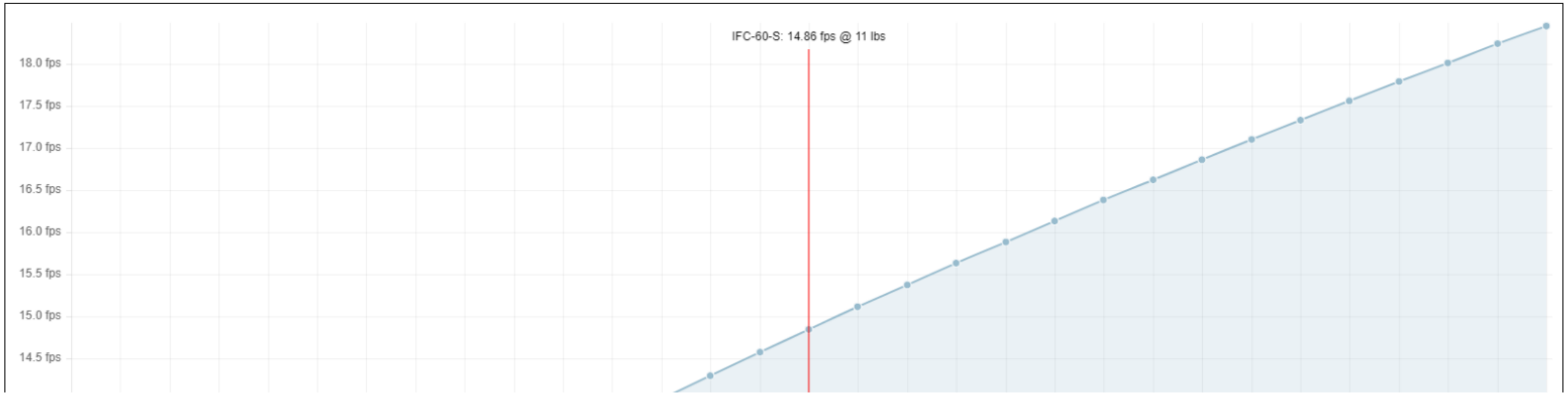
Cd (Projected):

Units:

Imperial

Update

Descent Rate vs Weight



SkyAngle™

"Rocket Recovery Redefined"

SkyAngle™ Parachutes -- Minimum Tube Compartment Length* (in inches)

*(When folded and packed per instructions. Does not include shock cord, suspension lines, FreeBag, Nomex® pad, wadding, etc. Measurements are nominal.)

Tube Size	29mm	38mm	54mm	2.56in	3.00in	3.90in	5.50in	6.00in	7.51in	11.41in
Chute Size										
Classic 20	*	8*	6	6	6	<6	-	-	-	-
Classic II 20	*	10*	7*	7	7	<6	-	-	-	-
Classic 24 (NEW!)	*	12	11	8	<7	-	-	-	-	-
Classic II 24	See CERT-3™ Drogue									
Classic 28	*	*	7	7	7	<7	-	-	-	-
Classic II 28	*	*	10	10	10	<10	-	-	-	-
Classic 32 (NEW!)	*	*	11	10	8	<8	-	-	-	-
Classic II 32 (NEW!)	*	*	12	11	10	<9	-	-	-	-
Classic 36	*	*	10*	10	8.5	<9	-	-	-	-
Classic II 36	*	*	*	11	10	<10	-	-	-	-
Classic 44	*	*	*	9	8	9	-	-	-	-
Classic II 44	*	*	*	12*	11	10	<10	-	-	-
Classic 52	*	*	*	*	11	9	<9	-	-	-
Classic II 52	*	*	*	*	13	10	<10	-	-	-
Classic 60	*	*	*	*	14	11	<11	-	-	-
Classic II 60	*	*	*	*	*	12	<12	-	-	-
CERT-3™ Drogue	*	*	7	7	7	<7	-	-	-	-
CERT-3 L	*	*	*	*	*	17	12	10	8	5
CERT-3 XL	*	*	*	*	*	25	15	14	11	5
CERT-3 XXL	*	*	*	*	*	33	25	16	12	6

*** = Does not fit, or very tight fit.** **- = Easy fit, minimum space required.** (rev 9/02)

	Results	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Optimal delay	Max. acceleratic Gees	Altitude at deplc Feet	Velocity at launc Miles / Hour	Velocity at deplc Miles / Hour	WeatherCocking
11		[M750W-Pluggec	8030.97	384.35	9.59	3.23	8030.97	23.66	15.26	Safe
12		[M4500ST-Plugg	6411.29	528.34	17.40	18.80	6411.29	61.79	17.53	Safe
13		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe
14		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8914.99	55.72	20.04	Safe
15		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe
16		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe
17		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe
18		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe
19		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe
20		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe
21		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe
22		[M2500T-Pluggec	8914.99	633.93	18.37	9.22	8915.00	55.72	20.04	Safe

Recovery system data

- P: Parachute Deployed at : 122.700 Seconds
- Velocity at deployment: 55.1709 MPH
- Altitude at deployment: 499.93290 Ft.
- Range at deployment: 1582.27882 Ft.
- P: Drogue Parachute Deployed at : 22.639 Seconds
- Velocity at deployment: 20.0385 MPH
- Altitude at deployment: 8915.00457 Ft.
- Range at deployment: 848.49632 Ft.

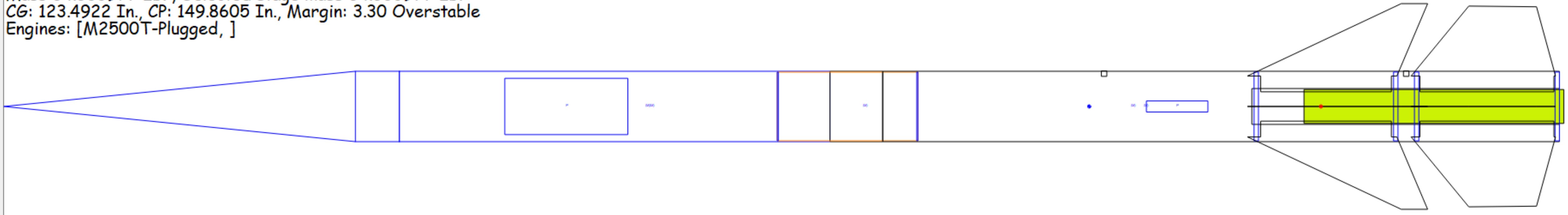
Time data

- Time to burnout: 4.265 Sec.
- Time to apogee: 22.639 Sec.
- Optimal ejection delay: 18.374 Sec.

Landing data

- Successful landing
- Time to landing: 146.736 Sec.
- Range at landing: 1758.54465
- Velocity at landing: Vertical: -13.8017 MPH , Horizontal: 5.0000 MPH , Magnitude: 14.6795 MPH

Length: 177.0000 In. , Diameter: 8.0000 In. , Span diameter: 27.0000 In.
Mass 64.603977 Lb. , Selected stage mass 64.603977 Lb.
CG: 123.4922 In., CP: 149.8605 In., Margin: 3.30 Overstable
Engines: [M2500T-Plugged,]



Key Design Requirements

Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.

Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down).

Quick tips to ensure you don't end up in this situation

- Do not design a rocket to meet the upper (lower) end of our allowed constraints.
- Do not fall in love with manufacturer ratings especially for parachute drag coefficients: Test, Test, Test!!!!!!
- Simulation data is good….but Raw flight data is better. "But our simulation said…."
- Descent rate is more important than descent mass: KE = (1/2) * mass * velocity squared
- Don't build bigger than you need
- Teams almost ALWAYS UNDERESTIMATE mass: Hardware, nuts, bolts, epoxies, threaded rods, u-bolts, eye-bolts, parachutes, shock cords

Stability

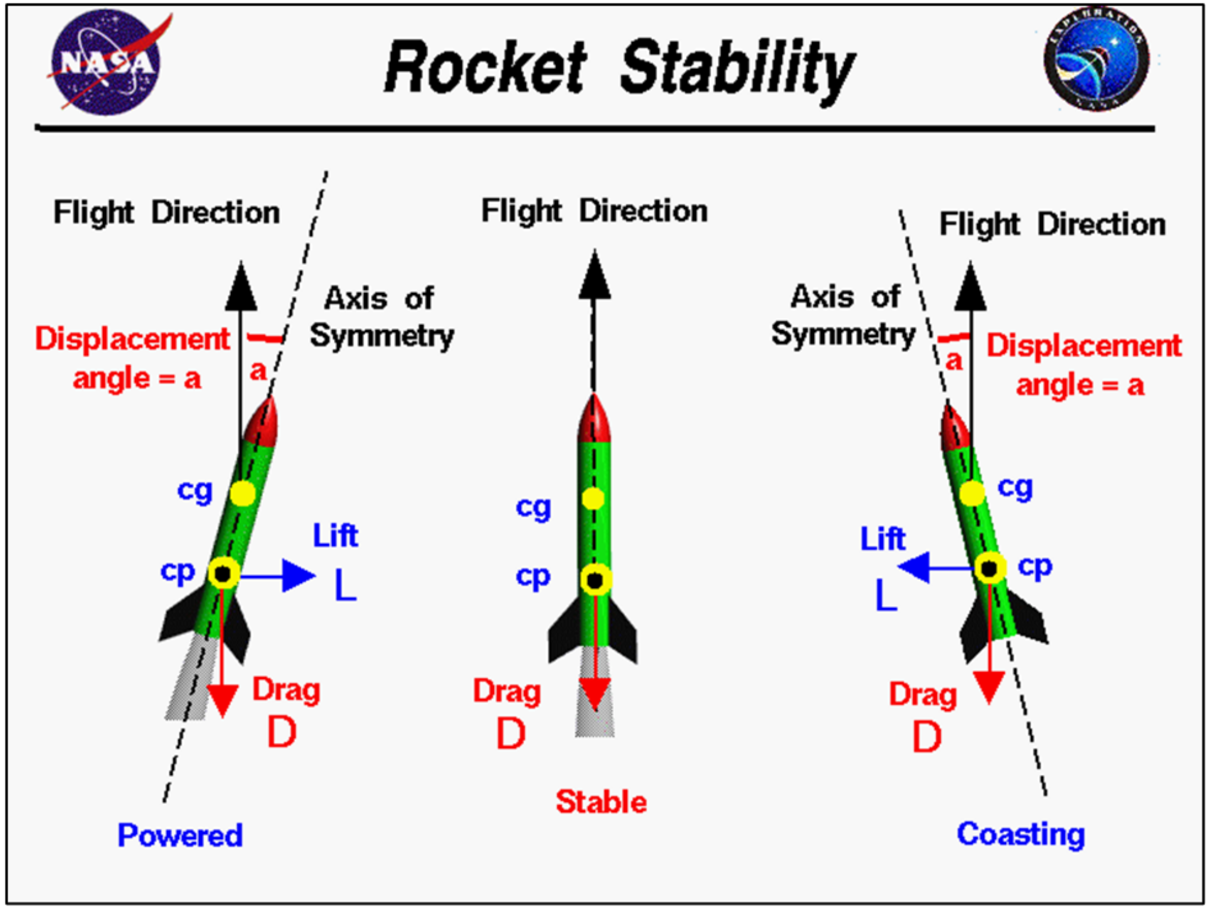
Stability:

An object is directionally stable if tends to return to its original direction in relation to the oncoming medium (water, air, etc.) when disturbed away from that direction

Also called “weathervaning”

Without stability, a rocket would tumble end over end, spin, or orient itself at a high angle of attack and the rocket may experience structural failure

A rocket is considered stable if its *Center of Gravity (CG)* is at least one body diameter in front of its *Center of Pressure (CP)*.



Stability: Static Margin

Static Margin:

Or *Margin of Stability* describes the directional stability of a rocket

$$S.M. = \frac{\bar{X}_{CP} - \bar{X}_{CG}}{Body\ Diameter} \geq 1.0$$

Recall:

- An object is directionally stable if tends to return to its original direction in relation to the oncoming medium (water, air, etc.) when disturbed away from that direction and
- A rocket is considered stable if its *Center of Gravity (CG)* is at least one body diameter in front of its *Center of Pressure (CP)*.

Generally, it is desirable to have a static margin of 1.5 to 2.0. A rocket is considered over stable if it has a static margin of 3.0 or greater. For NASA Student Launch we do require a minimum static stability margin (on the pad) of 2.0 or above.

An over stable rocket will lean or “weathervane” further into the wind and not travel as high.

Generally, the CG will move forward as a solid rocket motor burns, causing the rocket to become more stable.

Stability: Center of Gravity (CG)

Center of Gravity (CG):

The Center of Gravity of rigid body is the mean location of all the masses in a system

The CG can be determined analytically or empirically

The analytical method requires accounting for:

The individual point masses that compose the system

their location in the system as measured from the tip of a rocket's nose cone

The average of their positions weighted by their masses is the location of the center of gravity

$$(1)\ \bar{X}_{CG}W_{CG} = \sum_{i=1}^{n} W_i\bar{X}_i = W_1\bar{X}_1 + W_2\bar{X}_2 + W_3\bar{X}_3 + \cdots$$

$$(2)\ W_{CG} = \sum_{i=1}^{n} W_i = W_1 + W_2 + W_3 + \cdots$$

$$(3)\ \bar{X}_{CG} = \frac{\bar{X}_{CG}W_{CG}}{W_{CG}}$$

Component	Weight (W_i) (oz.)	Station $(\bar{X}_i)$ (in.)
Fiberglass Nosecone	3.4	6.5
Nosecone Mass	2	1
G10 Nosecone Bulkplate	0.3	10.5
Nosecone Eye-Bolt	0.8	10.5
Pre-slotted Fiberglass Airframe	7.7	21
12' Shock Cord	2	18
30" Parachute	1	15
9x9 Chute Protector	0.5	18
Forward G10 Centering Ring	0.2	26
Forward Centering Ring Eye-Bolt	0.2	26
38mm Motor Tube	2.3	31
G10 Fins (4x)	1.9	31
Aft Centering Ring	0.2	34
Aero Pack 38mm Motor Retainer	0.8	34
CT1 Pro 38-2G Case	3.5	30
CTI H225 Motor Reload	6.8	30

Stability: Center of Pressure (CP)

Center of Pressure (CP):

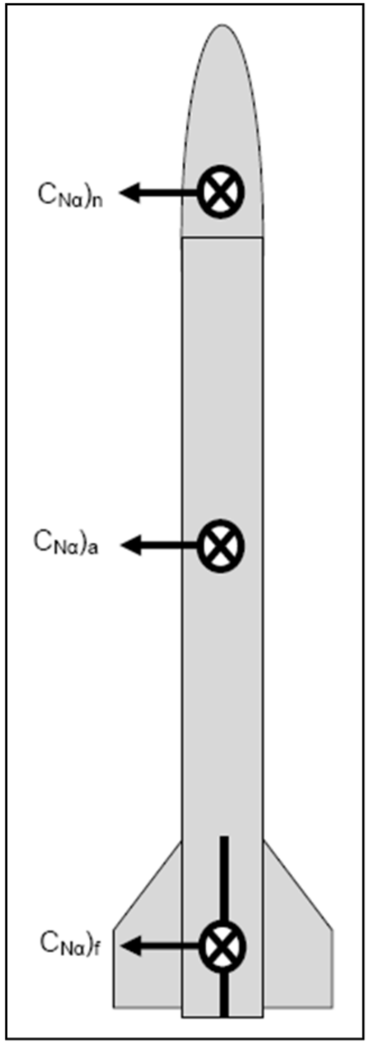
Aerodynamic forces act on all parts of the rocket. Those aerodynamic forces act through a single point called the Center of Pressure (CP).

CP can be determined by regional influence using algebraic forms of the Barrowman equations and accounting for:

- Each primary component's Normal Force ($C_{n\alpha}$)
- Their location in the system as measured from the tip of a rocket's nose cone

The basic assumptions used to calculate the theoretical CP for a rocket are:

- The angle of attack (α) of the rocket is near zero (less than 10^{o})
- The speed of the rocket is much less than the speed of sound
- The air flow over the rocket is smooth and does not change rapidly
- The rocket is thin compared to its length (L >> D)
- The nose of the rocket comes smoothly to a point
- The rocket is an axially symmetrical rigid body
- The fins are thin flat plates



How to "Fix" a Rocket

What happens if you build a rocket, and its stability margin is not safe to fly? Or its thrust to weight ratio is not sufficient?

No, you don't need to buy/build a new rocket!

- add weight to the front of the rocket. Remember, we need to shift the CG as far in front of the CP as possible (minimum one body tube diameter)
- choose a stronger motor
- lengthen the airframe (body tube) by adding a coupler
- lengthen the fins, moving the CP back

Computer Software to Aid in Rocket Design

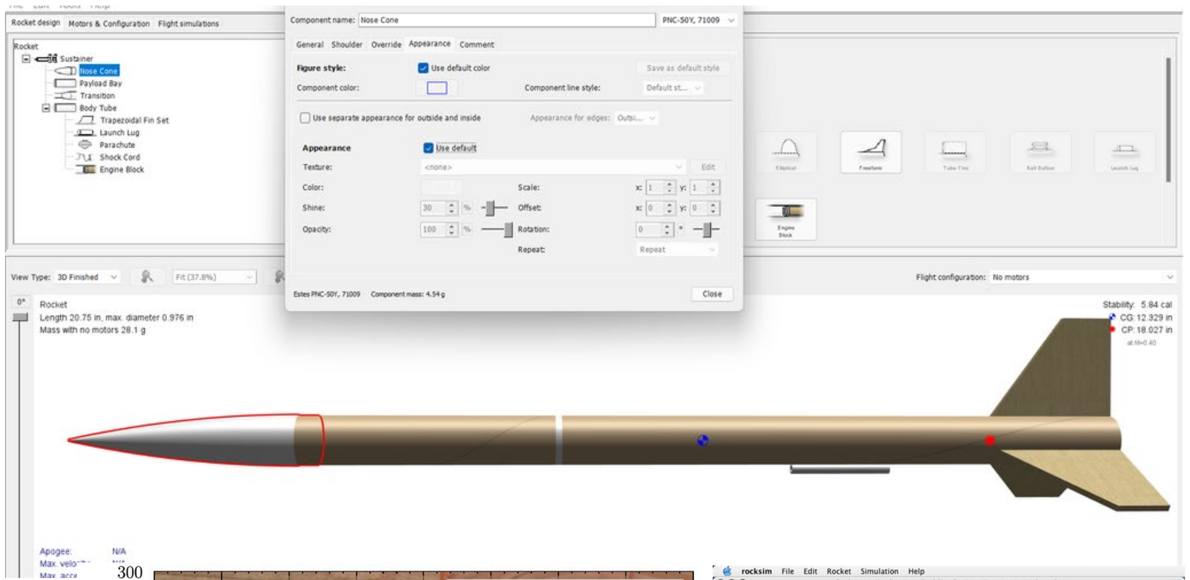
RockSim

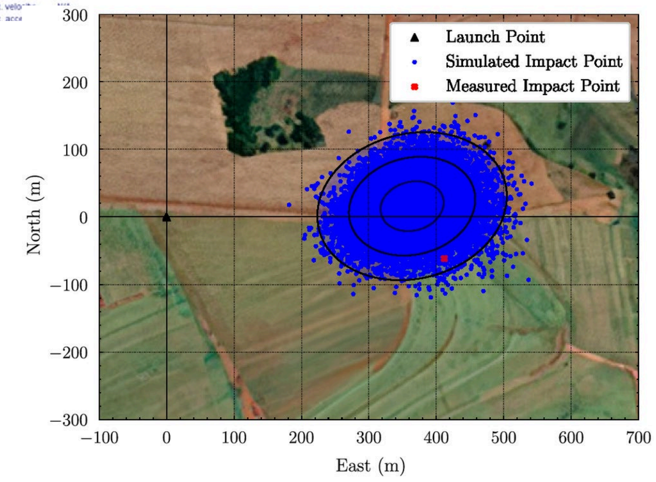
(free trial, otherwise paid license)

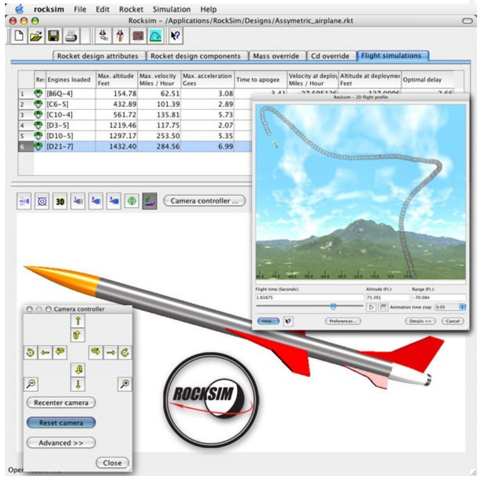
Open Rocket

(Opensource software very similar to RockSim)

RocketyPy library via Python





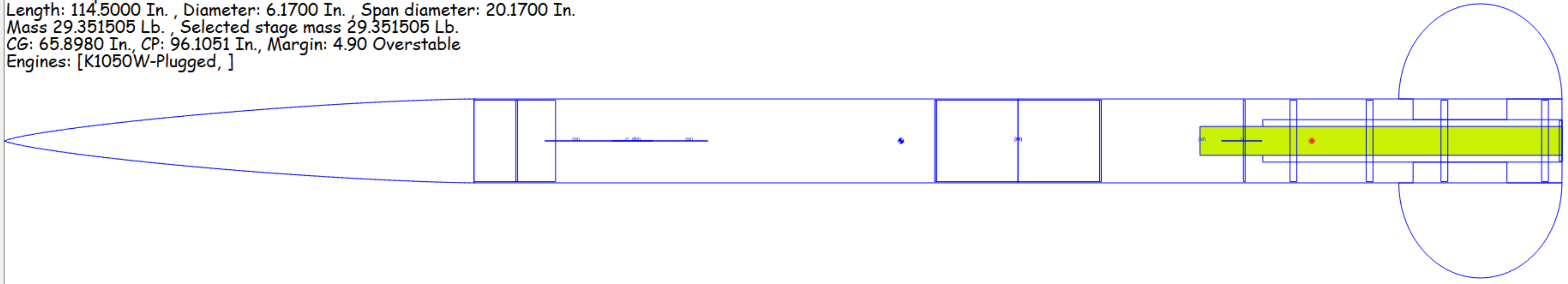


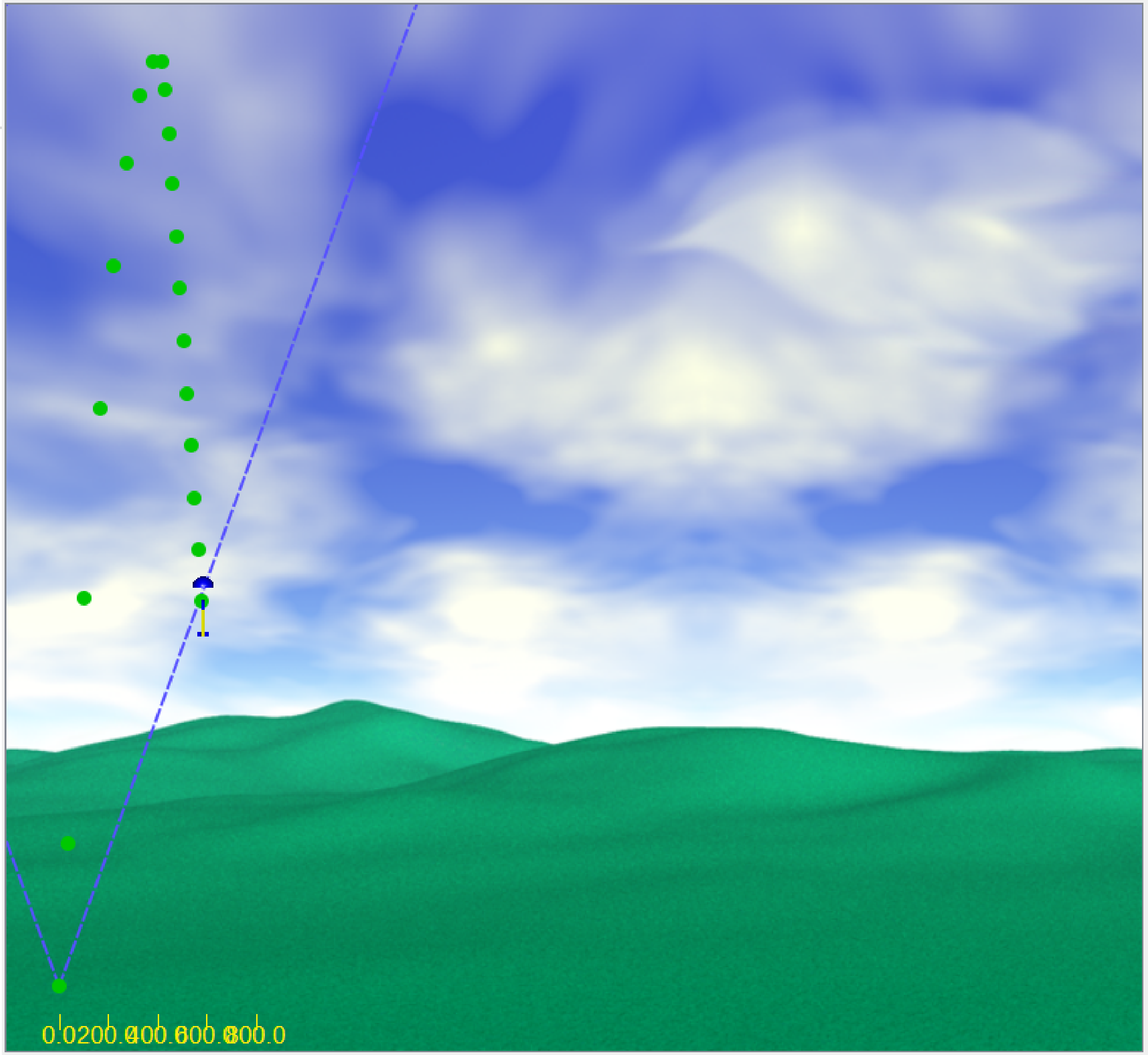
RockSim

Rocket design attributes | Rocket design components | Mass override | Cd override | Flight simulations | Recommended Motors

	Results	Engines loaded	Max. altitude Feet	Max. velocity Miles / Hour	Optimal delay	Max. acceleratic Gees	Altitude at deplc Feet	Velocity at launch guide departure Miles / Hour	Velocity at deployment Miles / Hour	WeatherCocking
1		[L1050BS-0]	5761.52	477.44	15.07	7.58	5761.52	23.98	30.53	Safe
2		[L1050BS-0]	5789.80	478.05	15.11	7.59	5789.80	23.98	30.48	Safe
3		[L1050BS-Plugge	5777.10	477.16	15.09	7.58	5777.11	49.02	16.56	Safe
4		[K1050W-Plugge	3755.54	367.76	12.65	9.83	3755.55	56.92	15.59	Safe
5		[K1050W-Plugge	3755.54	367.76	12.65	9.83	3755.55	56.92	15.59	Safe

K1050 Sample ARW
Length: 114.5000 In. , Diameter: 6.1700 In. , Span diameter: 20.1700 In.
Mass 29.351505 Lb. , Selected stage mass 29.351505 Lb.
CG: 65.8980 In., CP: 96.1051 In., Margin: 4.90 Overstable
Engines: [K1050W-Plugged,]



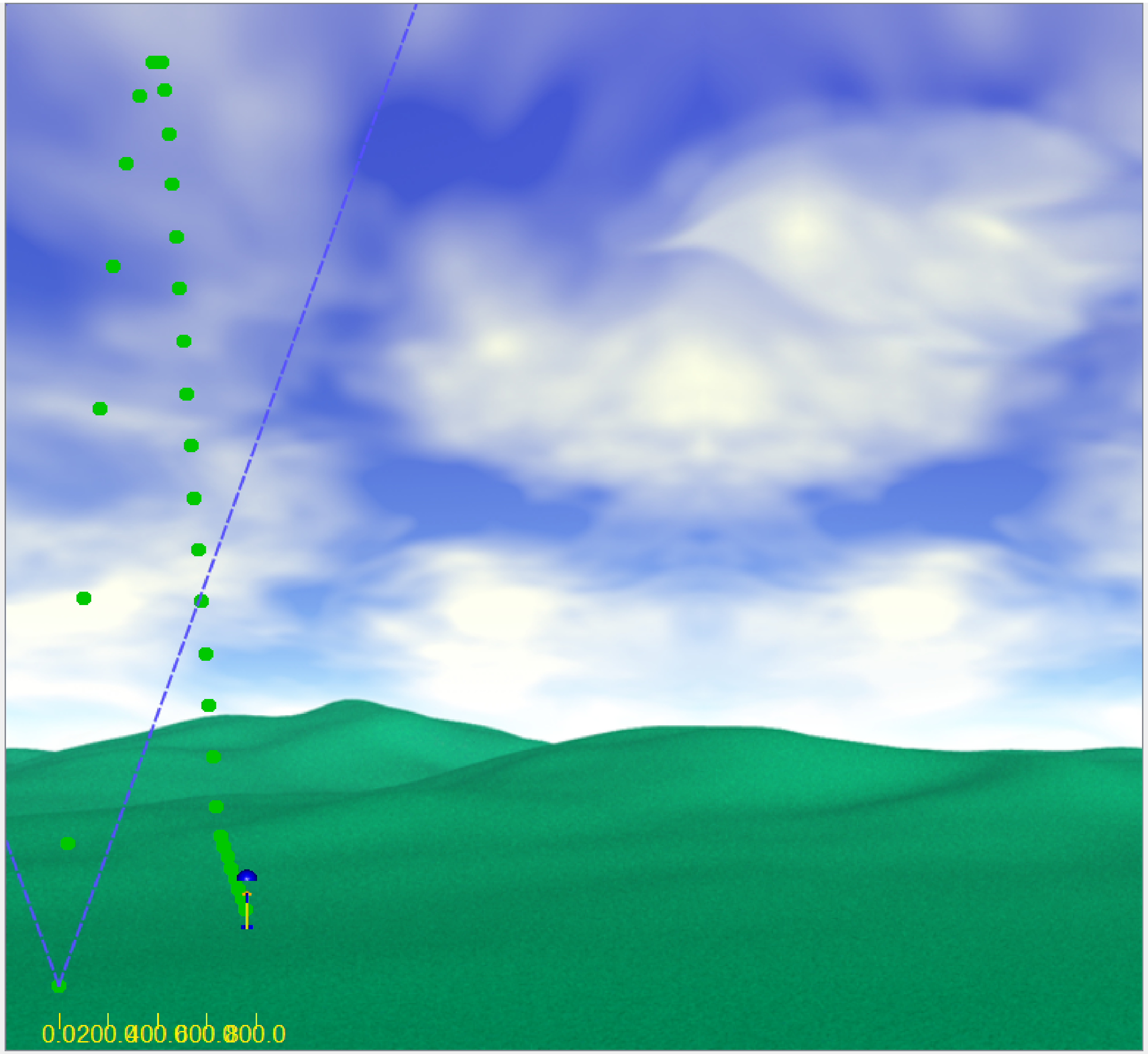


	Data value	Units
Time	39.0862	
Thrust	0	N
x-Thrust	0	N
y-Thrust	0	N
Acceleration	1.002	Gees
x-Acceleration	0	Gees
y-Acceleration	1.002	Gees
Acceleration Total	0.008	Gees
x-Acceleration Total	-0.006	Gees
y-Acceleration Total	0.005	Gees
Velocity	70.683	Miles / Hour
x-Velocity	5	Miles / Hour
y-Velocity	-70.506	Miles / Hour
Mach number	0.0933705	
Altitude	1486.32	Feet
Range	586.132	Feet
Cd	1.5	
Drag force	117.451	N
x-Drag force	-0.730472	N
y-Drag force	117.451	N
Longitudinal moment of inertia	51123.6	Pounds (Avdp.)-Inches
Radial moment of inertia	193.206	Pounds (Avdp.)-Inches
Flight angle	90	Deg.
Gamma - Velocity tangent angle	-85.9436	Deg.
Wind angle of attack	0	Deg.
CG	61.875	Inches
Mass	26.3484	Pounds (Avdp.)
CP	74.076	Inches
CNa - normal force coefficient	13.9747	
Static stability margin	1.97748	Calibers
Angular acceleration	0	Rad/s/s
Torque	0	N-m
Pitch rate	0	rad/s

Flight time (Seconds): 39.0862

Altitude (Ft.): 1486.32

Range (Ft.): 586.132



	Data value	Units
Time	63.2887	
Thrust	0	N
x-Thrust	0	N
y-Thrust	0	N
Acceleration	0.998	Gees
x-Acceleration	0	Gees
y-Acceleration	0.998	Gees
Acceleration Total	0.006	Gees
x-Acceleration Total	-0.006	Gees
y-Acceleration Total	0	Gees
Velocity	15.119	Miles / Hour
x-Velocity	5	Miles / Hour
y-Velocity	-14.268	Miles / Hour
Mach number	0.0198888	
Altitude	298.251	Feet
Range	763.617	Feet
Cd	2.2	
Drag force	116.908	N
x-Drag force	-0.730472	N
y-Drag force	116.908	N
Longitudinal moment of inertia	51123.6	Pounds (Avdp.)-Inches
Radial moment of inertia	193.206	Pounds (Avdp.)-Inches
Flight angle	90	Deg.
Gamma - Velocity tangent angle	-70.6877	Deg.
Wind angle of attack	0	Deg.
CG	61.875	Inches
Mass	26.3484	Pounds (Avdp.)
CP	74.076	Inches
CNa - normal force coefficient	13.9747	
Static stability margin	1.97748	Calibers
Angular acceleration	0	Rad/s/s
Torque	0	N-m
Pitch rate	0	rad/s
Pitch force	0	N

Flight time (Seconds): 63.2887

Altitude (Ft.): 298.251

Range (Ft.): 763.617

Questions?

NASA