NOVEMBER 30, 2018

Revision 2

CFD ANALYSIS OF PRELIMINARY OPENROCKET DESIGN FOR 30K

HELEN II

BEN APPLEBY

PROJECT SUNRIDE

Abstract

This report outlines the aerodynamic characteristics of the preliminary design for the HELEN II rocket, simulating cases at subsonic, transonic and maximum velocity. Through this, the drag coefficient for subsonic flight and the drag coefficient changed caused by transonic wave drag can be characterized. This will enable the design and propulsion team to further refine the OpenRocket design and produce flight models.

Overview

Maximum Velocity Drag Case

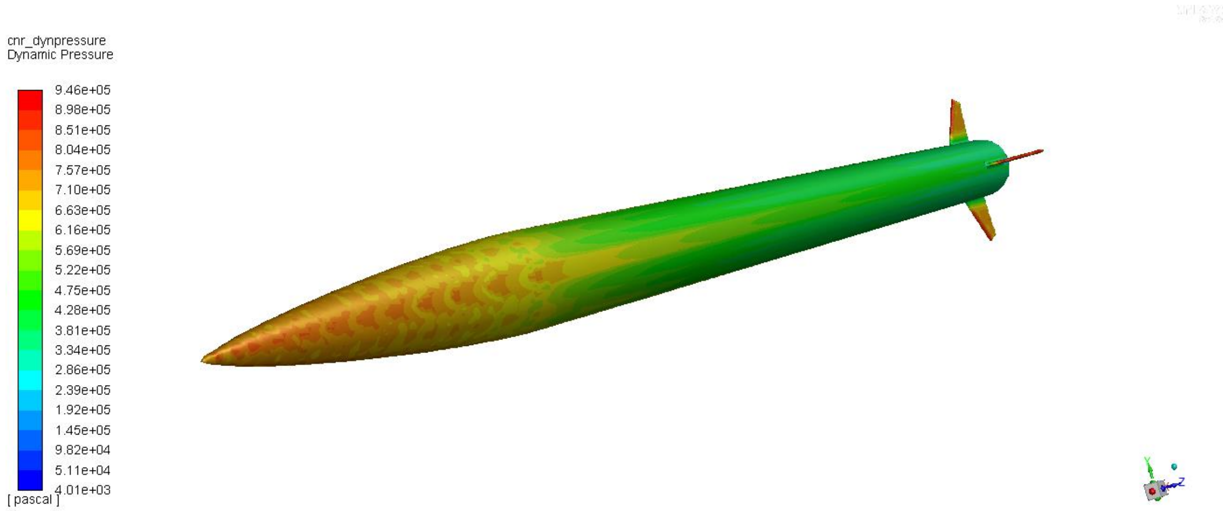
Forces - Direction Vector (1 0 0)

	Forces (n)			Coefficients		
Zone	Pressure	Viscous	Total	Pressure	Viscous	Total
rocket_wall	3954.5412	1231.5589	5186.1001	6456.3937	2010.7085	8467.1022
Net	3954.5412	1231.5589	5186.1001	6456.3937	2010.7085	8467.1022

ANSYS Fluent produced an output for the overall drag profile of the rocket, showing that 3954N of drag was caused by the pressure forces acting on the rocket, and 1231N were caused by viscous forces. The viscous drag is caused by the rocket's profile drag, which at a velocity of 645m/s and density of 1.225kg/m^3 yields a viscous drag coefficient of 0.004833.

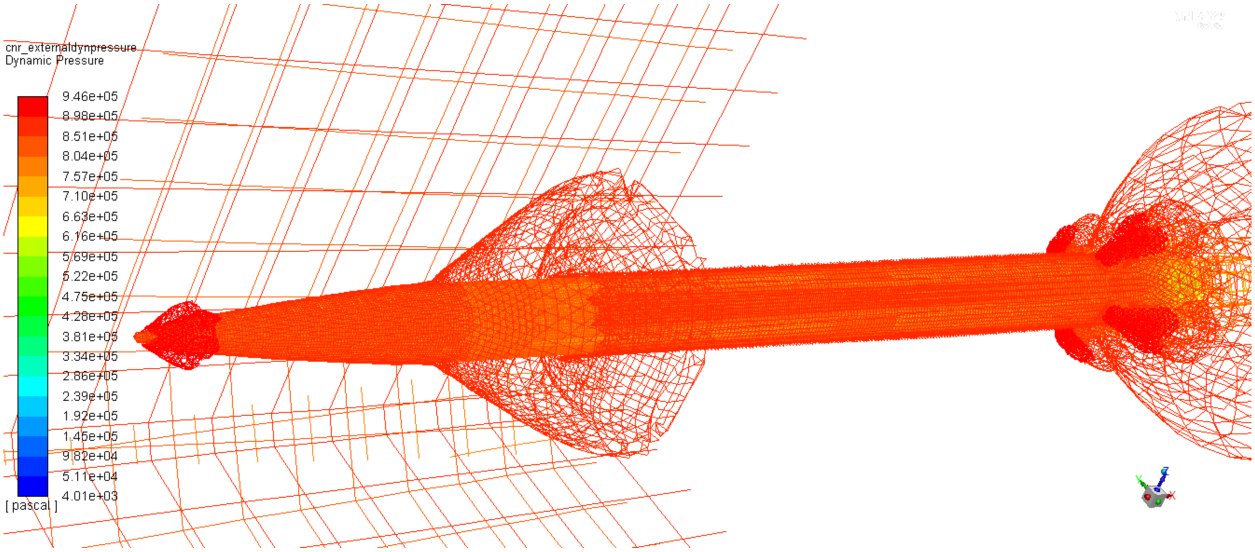
Due to the absence of lifting surfaces on the rocket, the primary cause for pressure drag acting upon the rocket is from system of shockwaves that form around the rocket in flight.

CFD Results – Maximum Velocity Case (Mach 1.95)

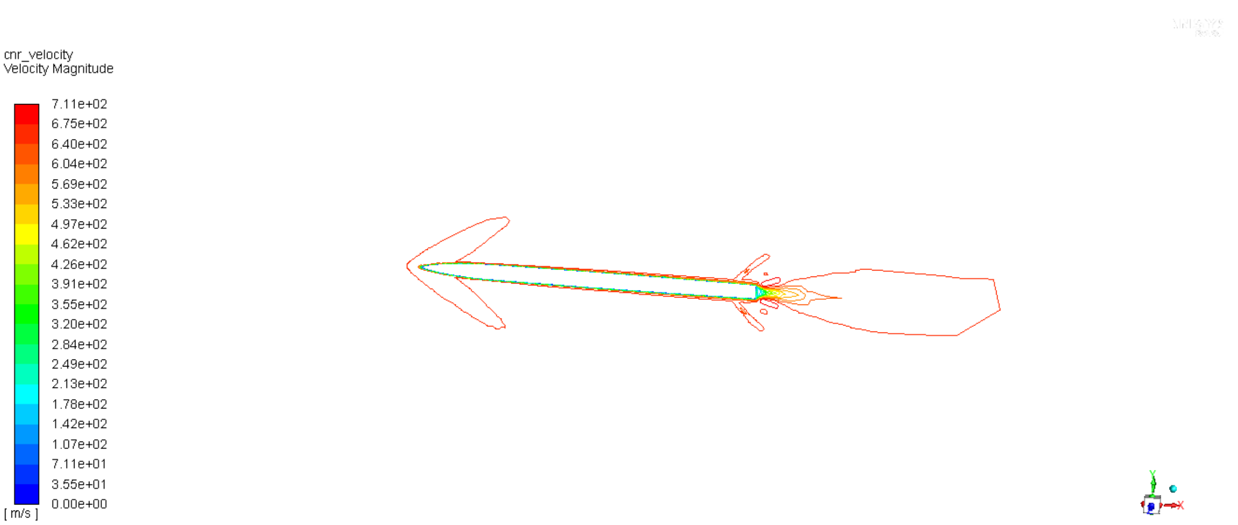


This contour shows the areas of greatest dynamic pressure along the rocket, being the nosecone and fins. This is determined by the skin friction coefficient as shown below:

Overleaf is shown the system of shockwaves that form around the profile of HELEN, causing most of the drag. The 2D cross sections show that the most prominent shock is that at the leading edge of the nose, forming a strong oblique shockwave and causing an increase in the local air density.


cnr_externaldynpressure
Dynamic Pressure
9.46e+05
8.98e+05
8.51e+05
8.04e+05
7.57e+05
7.10e+05
6.63e+05
6.16e+05
5.69e+05
5.22e+05
4.75e+05
4.28e+05
3.81e+05
3.34e+05
2.86e+05
2.39e+05
1.92e+05
1.45e+05
9.82e+04
5.11e+04
4.01e+03
[pascal]

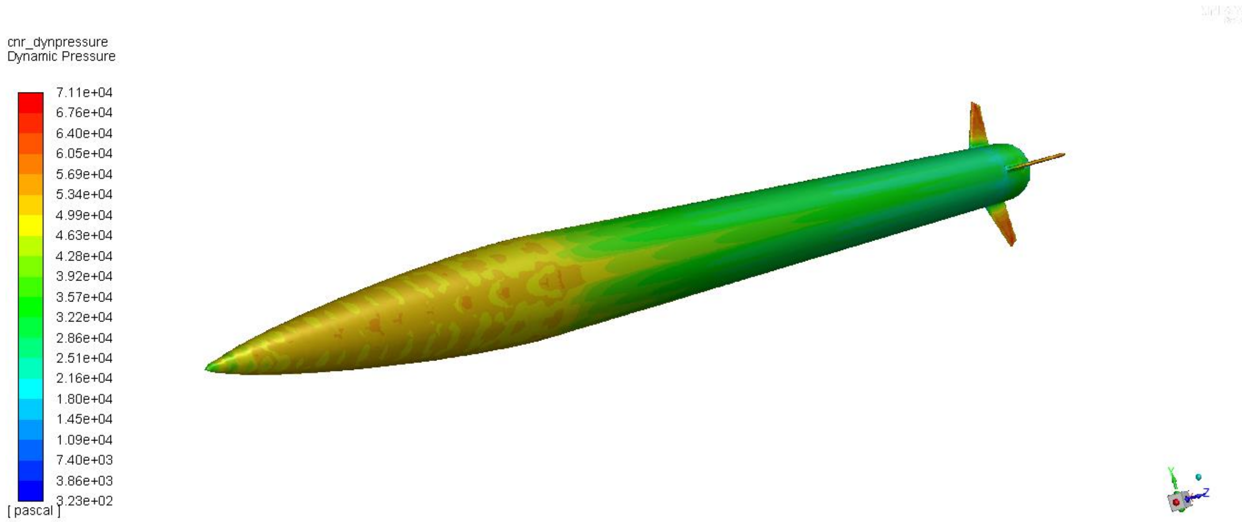

cnr_shock
Density
7.08e+00
6.78e+00
6.47e+00
6.16e+00
5.86e+00
5.55e+00
5.25e+00
4.94e+00
4.63e+00
4.33e+00
4.02e+00
3.72e+00
3.41e+00
3.10e+00
2.80e+00
2.49e+00
2.19e+00
1.88e+00
1.57e+00
1.27e+00
9.62e-01
[kg/m3]

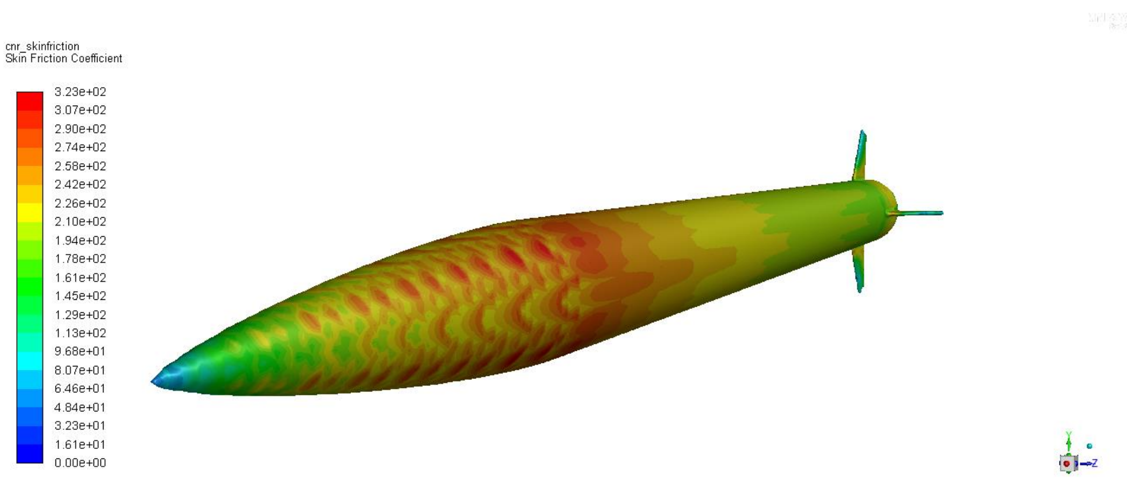

cnr_velocity
Velocity Magnitude
7.11e+02
6.75e+02
6.40e+02
6.04e+02
5.69e+02
5.33e+02
4.97e+02
4.62e+02
4.26e+02
3.91e+02
3.55e+02
3.20e+02
2.84e+02
2.49e+02
2.13e+02
1.78e+02
1.42e+02
1.07e+02
7.11e+01
3.55e+01
0.00e+00
[m/s]

CFD Results – Mach 1 Case

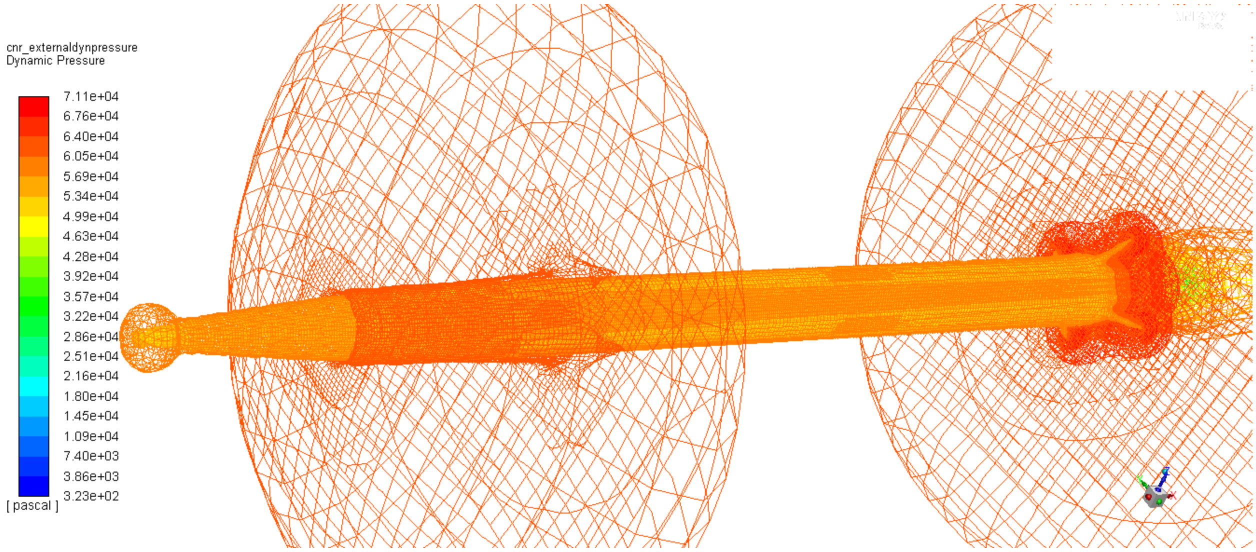
Forces - Direction Vector (1 0 0)

	Forces (n)			Coefficients		
Zone	Pressure	Viscous	Total	Pressure	Viscous	Total
rocket_wall	267.74952	128.25617	396.00569	437.14208	209.39783	646.53991
Net	267.74952	128.25617	396.00569	437.14208	209.39783	646.53991

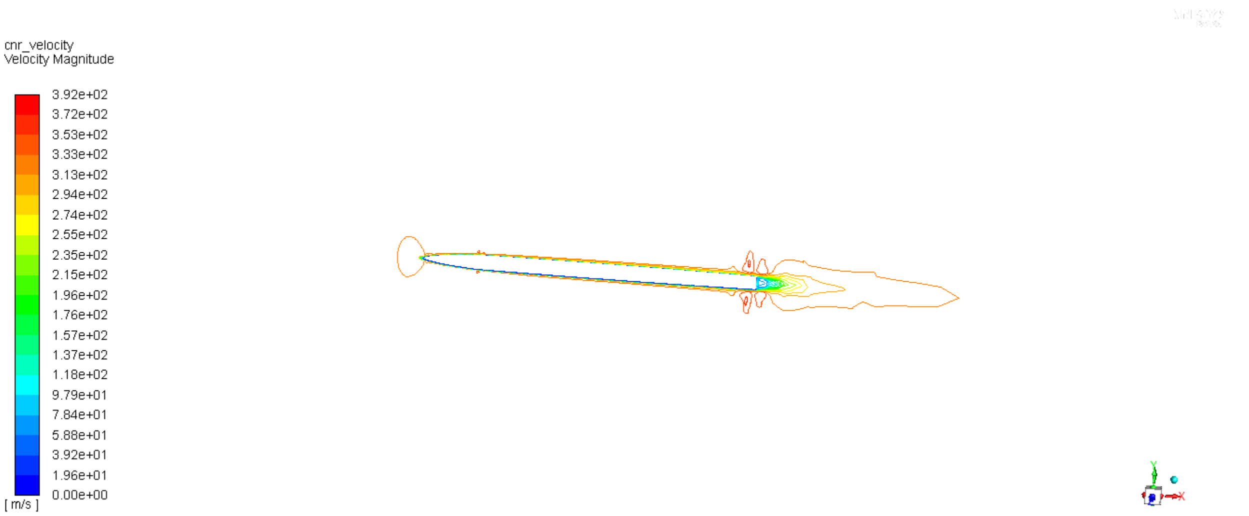




The skin friction characteristics for the Mach 1 case show that the viscous drag behavior is almost identical to the maximum velocity case. Thus, the profile drag coefficient can be deduced at either speed. Overleaf, the shockwave characteristics of the Mach 1 case show a series of torus-shaped pressure waves, caused by the normal shockwave at the nose of HELEN.


cnr_externaldynpressure
Dynamic Pressure
7.11e+04
6.76e+04
6.40e+04
6.05e+04
5.69e+04
5.34e+04
4.99e+04
4.63e+04
4.28e+04
3.92e+04
3.57e+04
3.22e+04
2.86e+04
2.51e+04
2.16e+04
1.80e+04
1.45e+04
1.09e+04
7.40e+03
3.86e+03
3.23e+02
[pascal]

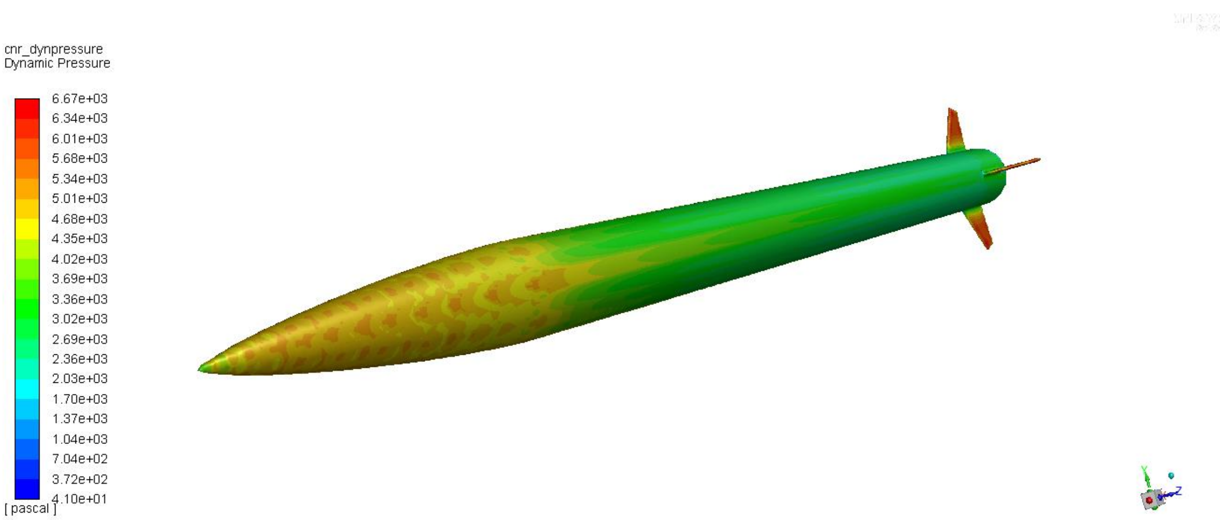

cnr_shock
Density
1.41e+00
1.38e+00
1.34e+00
1.31e+00
1.28e+00
1.24e+00
1.21e+00
1.17e+00
1.14e+00
1.11e+00
1.07e+00
1.04e+00
1.00e+00
9.70e-01
9.36e-01
9.02e-01
8.68e-01
8.34e-01
8.00e-01
7.66e-01
7.32e-01
[kg/m3]


cnr_velocity
Velocity Magnitude
3.92e+02
3.72e+02
3.53e+02
3.33e+02
3.13e+02
2.94e+02
2.74e+02
2.55e+02
2.35e+02
2.15e+02
1.96e+02
1.76e+02
1.57e+02
1.37e+02
1.18e+02
9.79e+01
7.84e+01
5.88e+01
3.92e+01
1.96e+01
0.00e+00
[m/s]

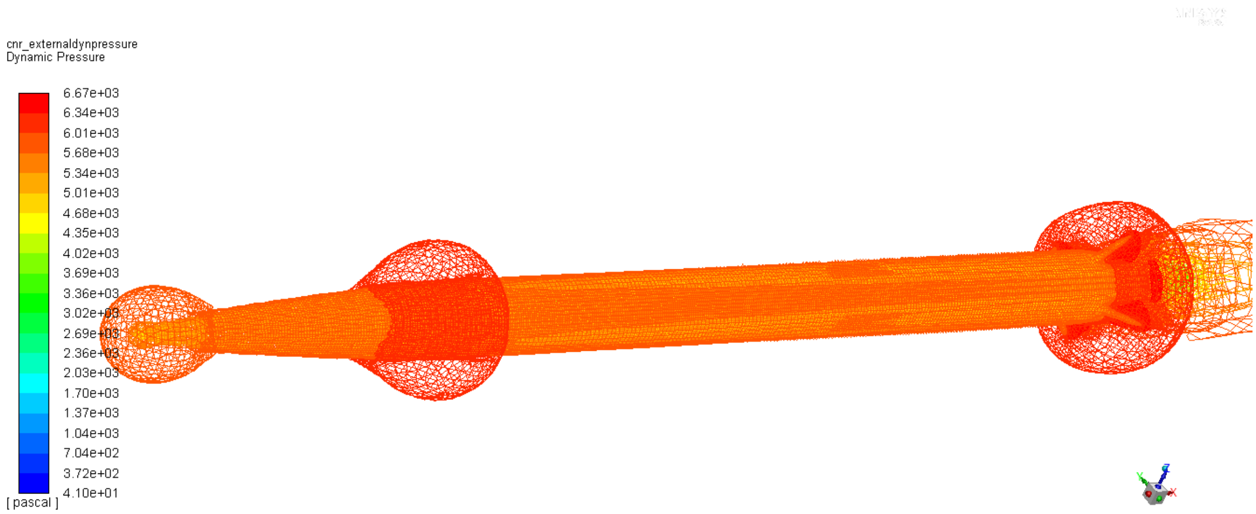
CFD Results – Mach 0.3 (~100m/s) Case

Forces - Direction Vector (1 0 0)

	Forces (n)			Coefficients		
Zone	Pressure	Viscous	Total	Pressure	Viscous	Total
rocket_wall	19.611344	15.917014	35.528358	32.018521	25.986961	58.005482
Net	19.611344	15.917014	35.528358	32.018521	25.986961	58.005482



As both previous cases, viscous drag behavior is the same for subsonic cases. Thus, it can be deduced that the viscous drag coefficient can be calculated at all speeds, to determine the form drag. Since the material properties have been left as aluminum, these coefficients can be calculated in further testing. Overleaf shows the pressure waves are significantly smaller in size and magnitude, due to the absence of a strong normal/oblique shockwave.


cnr_externaldynpressure
Dynamic Pressure
6.67e+03
6.34e+03
6.01e+03
5.68e+03
5.34e+03
5.01e+03
4.68e+03
4.35e+03
4.02e+03
3.69e+03
3.36e+03
3.02e+03
2.69e+03
2.36e+03
2.03e+03
1.70e+03
1.37e+03
1.04e+03
7.04e+02
3.72e+02
4.10e+01
[pascal]


cnr_shock
Density
1.19e+00
1.19e+00
1.19e+00
1.19e+00
1.18e+00
1.18e+00
1.18e+00
1.17e+00
1.17e+00
1.17e+00
1.17e+00
1.16e+00
1.16e+00
1.16e+00
1.16e+00
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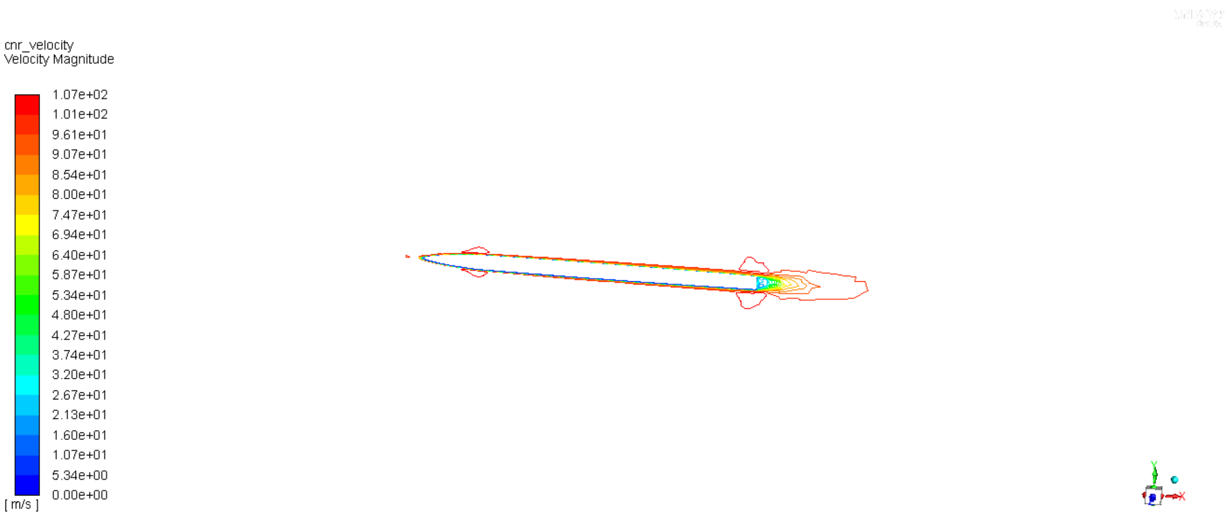
1.14e+00
1.14e+00
[kg/m3]


cnr_velocity
Velocity Magnitude
1.07e+02
1.01e+02
9.61e+01
9.07e+01
8.54e+01
8.00e+01
7.47e+01
6.94e+01
6.40e+01
5.87e+01
5.34e+01
4.80e+01
4.27e+01
3.74e+01
3.20e+01
2.67e+01
2.13e+01
1.60e+01
1.07e+01
5.34e+00
0.00e+00
[m/s]

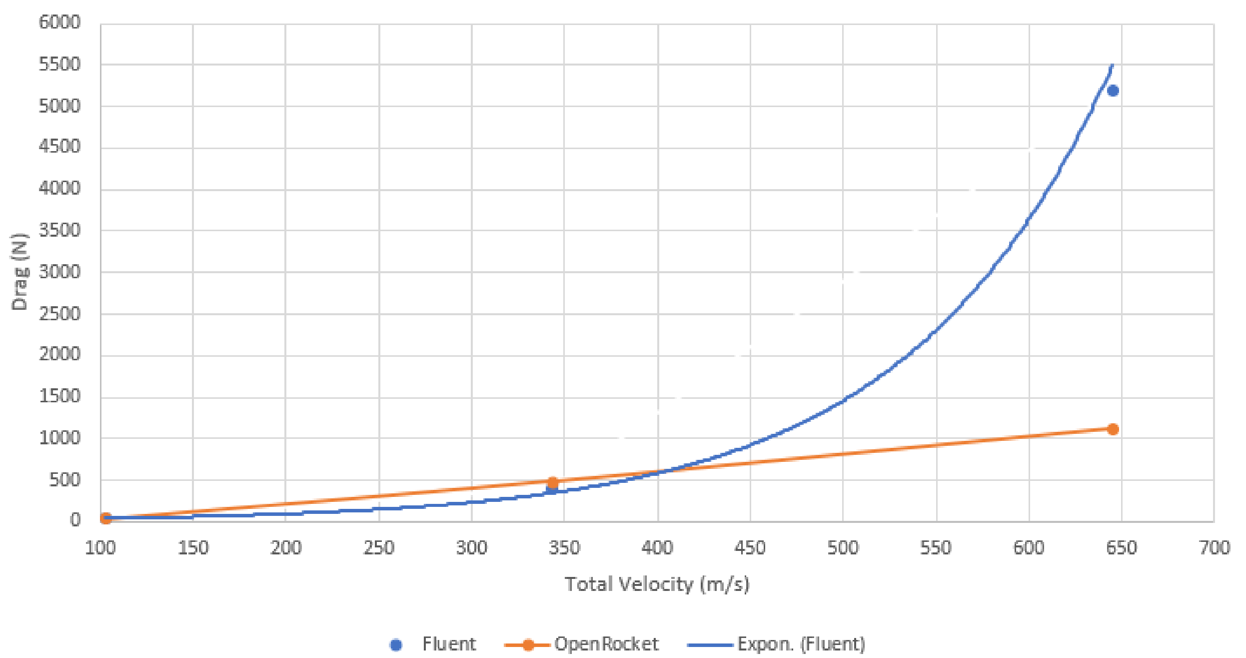
Results & Analysis

Velocity (m/s)	Viscous Drag	Pressure Drag	Total Drag	$C_{D, Visc}$	$C_{D, Pres.}$
102.9	15.917	19.611	35.528	0.002454	0.003024
343	128.256	267.750	396.006	0.00178	0.003716
645	1231.559	3954.5412	5186.100	0.004833	0.015519

Using the values obtained, the coefficients of drag can be calculated through the equation:

$$C_D = \frac{D}{\frac{1}{2}\rho V^2}$$

Shown is a plot of the total drag acting upon the rocket for both OpenRocket and Fluent simulations.



This shows that OpenRocket models drag as linear relationship and does not simulate the exponential drag behavior that occurs throughout the flight regime. At maximum velocity, the calculated drag is out by 4000N, thus further modelling of the rocket's flight regime is necessary. It is likely that this will not be necessary with AMY II, as the velocity is closer to Mach 1 and thus OpenRocket's drag modelling is sufficient.

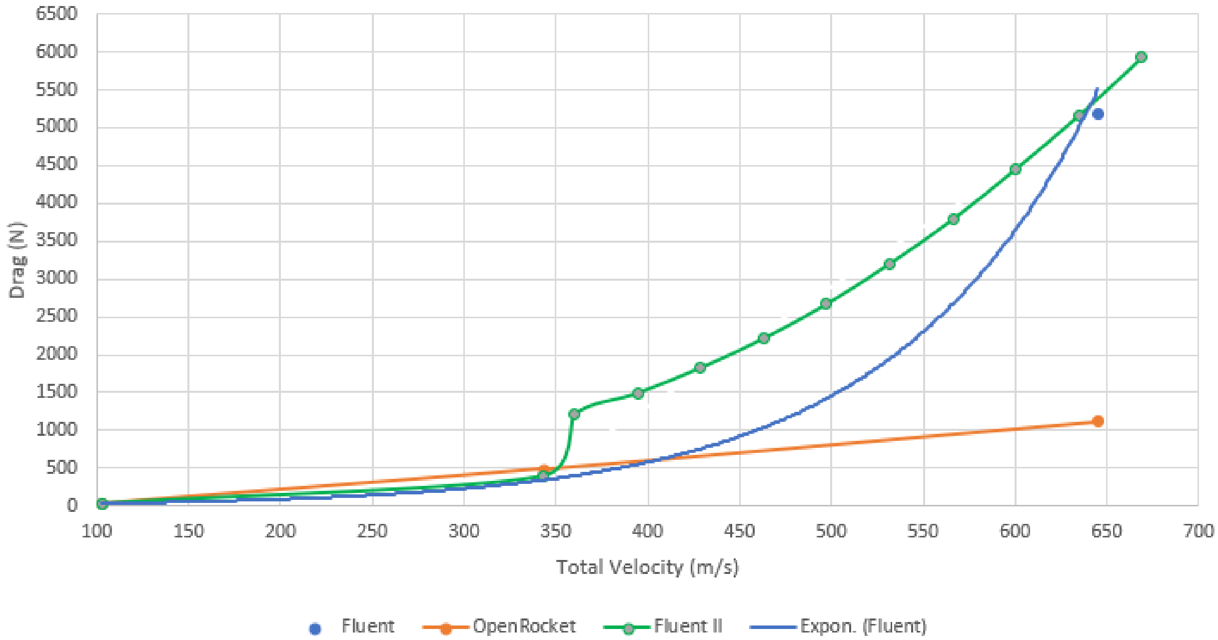
Below are the drag coefficient predictions for Mach 0.3, Mach 1 and Mach 1.95 respectively. These coefficients differ to the ones calculated earlier, as the methodology is different. (Likely incorporating plan form area)

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose cone	0.00 (0%)	0.00 (0%)	0.05 (10%)	**0.05 (11%)**
Body tube	0.00 (0%)	0.00 (0%)	0.04 (9%)	**0.04 (9%)**
Body tube	0.00 (0%)	0.00 (0%)	0.01 (3%)	**0.01 (3%)**
Body tube	0.00 (0%)	0.13 (27%)	0.21 (44%)	**0.34 (71%)**
Freeform fin set	0.00 (1%)	0.00 (0%)	0.03 (5%)	**0.03 (6%)**
Total	**0.00 (1%)**	**0.13 (27%)**	**0.35 (72%)**	**0.48 (100%)**

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose cone	0.02 (2%)	0.00 (0%)	0.04 (7%)	**0.06 (9%)**
Body tube	0.00 (0%)	0.00 (0%)	0.04 (6%)	**0.04 (6%)**
Body tube	0.00 (0%)	0.00 (0%)	0.01 (2%)	**0.01 (2%)**
Body tube	0.00 (0%)	0.25 (39%)	0.19 (29%)	**0.43 (68%)**
Freeform fin set	0.07 (11%)	0.00 (0%)	0.02 (4%)	**0.10 (15%)**
Total	**0.09 (14%)**	**0.25 (39%)**	**0.30 (47%)**	**0.64 (100%)**

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose cone	0.00 (0%)	0.00 (0%)	0.03 (7%)	**0.03 (7%)**
Body tube	0.00 (0%)	0.00 (0%)	0.03 (6%)	**0.03 (6%)**
Body tube	0.00 (0%)	0.00 (0%)	0.01 (2%)	**0.01 (2%)**
Body tube	0.00 (0%)	0.13 (30%)	0.13 (29%)	**0.26 (59%)**
Freeform fin set	0.10 (22%)	0.00 (0%)	0.02 (4%)	**0.11 (26%)**
Total	**0.10 (22%)**	**0.13 (30%)**	**0.21 (48%)**	**0.44 (100%)**

Updated CFD Simulation Results



Mach	Velocity (m/s)	Drag (N)
1.95	668.85	5923.4
1.85	634.55	5159.1
1.75	600.25	4452.9
1.65	565.95	3785.6
1.55	531.65	3200.4
1.45	497.35	2666.9
1.349942	463.03	2211.4
1.25	428.75	1823.5
1.15	394.45	1488.8
1.05	360.15	1203.7
1	343	396.006
0.3	102.9	35.528

Further transient testing will be appended to an updated version of this report, using a slightly more accurate numerical model and observing behavior at more velocities. This report is up-to-date as of 30/11/2018.