Analysis of Drag Created by Portland State Aerospace Society's Camera Ring Module and its Impact on Theoretical Maximum Achievable Altitudes Using Computational Fluid Dynamics in STAR CCM+

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Overview

The Portland State Aerospace Society (PSAS) is constantly striving to add new improvements and features to their rockets, commonly referred to as launch vehicles, to further their reach both literally and figuratively. One of the latest components to fly aboard PSAS' last launch vehicle, LV3, was a module comprised of 6 small cameras with wide fields of view, as shown in Figure 1. This enabled post processing of the footage into a 360° view of the launch and recovery of LV3.

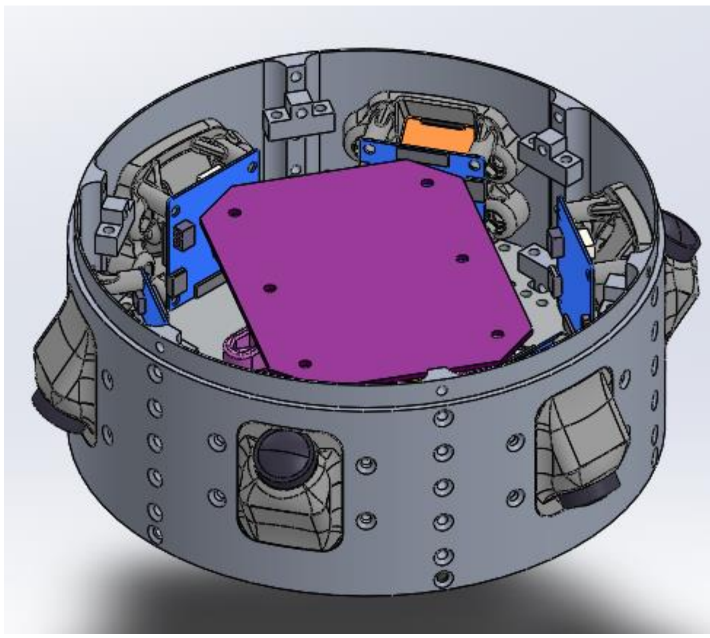

Figure 1: PSAS LV3 Camera Ring Module

The rocket body is comprised of a 6.6" diameter cylinder, topped with a nose cone whose curvature is prescribed by the LD-Haack Series to minimize drag. The cameras & housing protrude 0.5", with a width of 1".

This paper aims to explore the aerodynamic impacts of the protruding camera modules by modeling the flow over the nose cone and camera ring modules, and measuring the drag coefficient of the camera ring. The protruding features are likely to cause streamline separation and vortex shedding, which should be minimized in order to keep drag minimized and avoid any potential for tipping the rocket into unwanted spin or creating shockwaves as the rocket transitions from subsonic to supersonic speeds. A discussion of the impact of the additional drag is found in the results and discussion section.

Physical Model and Boundary Conditions

The objects of interest to this study are the camera modules protruding from the camera ring. These can be seen in Figures 2 & 3; units are in inches. For simplification, the cross sectional area was taken to be 0.5 in^2, and is used later to calculate drag coefficients for both camera orientations.

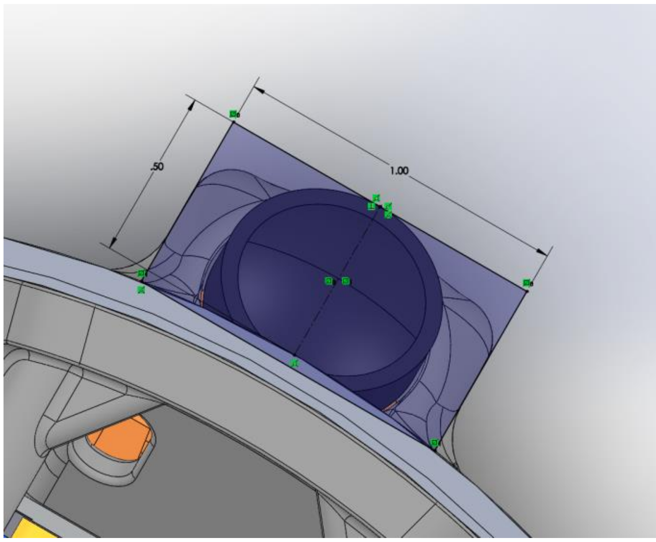

Figure 2: Camera module face on

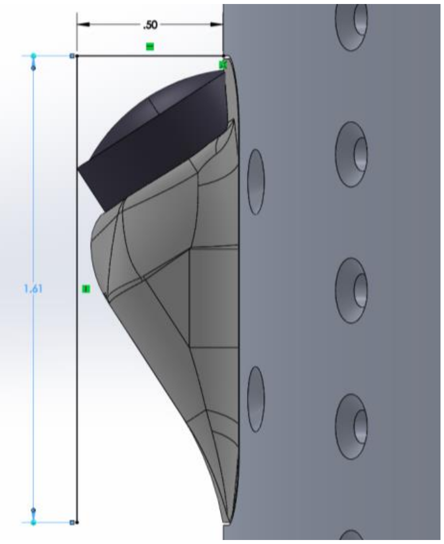

Figure 3: Camera module side view

In order to save on computational power and reduce overall complexity, the simplified nose cone and camera module shown in Figure 4 were used to generate the fluid volume for STAR CCM+; units are in inches.

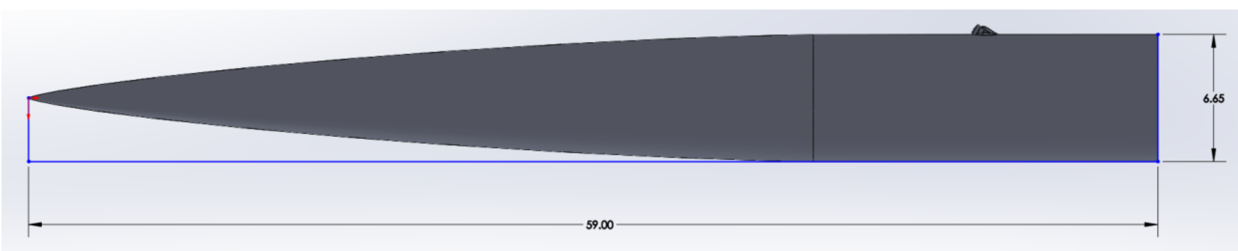

Figure 4: Simplified nose cone and camera module

A fluid region was created using a large cylinder and the cavity feature in Solidworks. Since the rocket is symmetrical, a 15° slice of the region was extracted and exported as a parasolid model for use with STAR CCM+, as seen in Figure 5. This region split the single camera module in half, and symmetry planes were used in STAR CCM+ to model the other half of the module. Table 1 shows the boundary conditions used.

Table 1: Boundary Conditions

Inlet Velocity	200m/s
Constant Temperature	300K
Initial Outlet Pressure	0 Pa

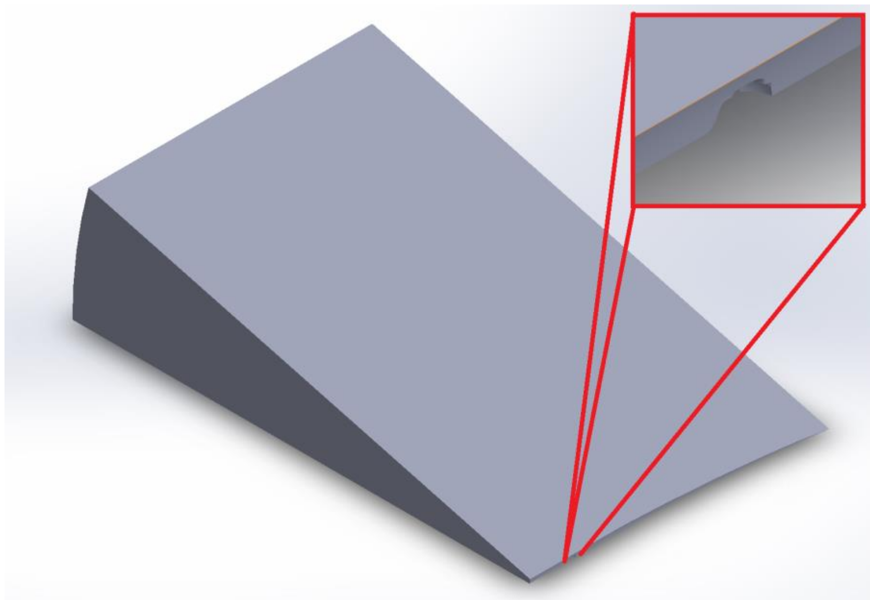

Figure 5: Fluid Region with breakout highlighting camera module cutout

CFD Software Features

The choices for the modeling procedure in STAR CCM+ were made to keep the model as simple as possible while allowing the flow to be visualized and the residuals to converge. A basic trimmer mesh with prism layers was applied to the fluid region, with a base size of 5cm. The nose cone and camera features, being much smaller, were modeled using independent meshes varying in size from 1-4mm. The fluid properties are the default for air, and set to behave as an ideal gas. The coupled flow solver was used and a Courant Number of 100 was used to assist in convergence. The outermost wall was set to have a slip condition to better idealize the far field state of an external flow. Grid sequencing was also used to initialize the simulation, which prevented divergence during the early iterations. The inlet was set to a velocity inlet, with a speed of 200 m/s. The outlet was set as a simple outlet. Drag coefficients were measured using the Force Coefficient report, using the boundary conditions previously described.

Three total simulations were created. One for the camera modules facing upwards, one for the camera modules facing downwards, and one for a concept cover for the cameras geared at reducing drag.

CFD Mesh

Figure 6 shows the trimmer mesh that is valid for all 3 simulations, which is a coarse mesh that refines near the camera and nose cone features.

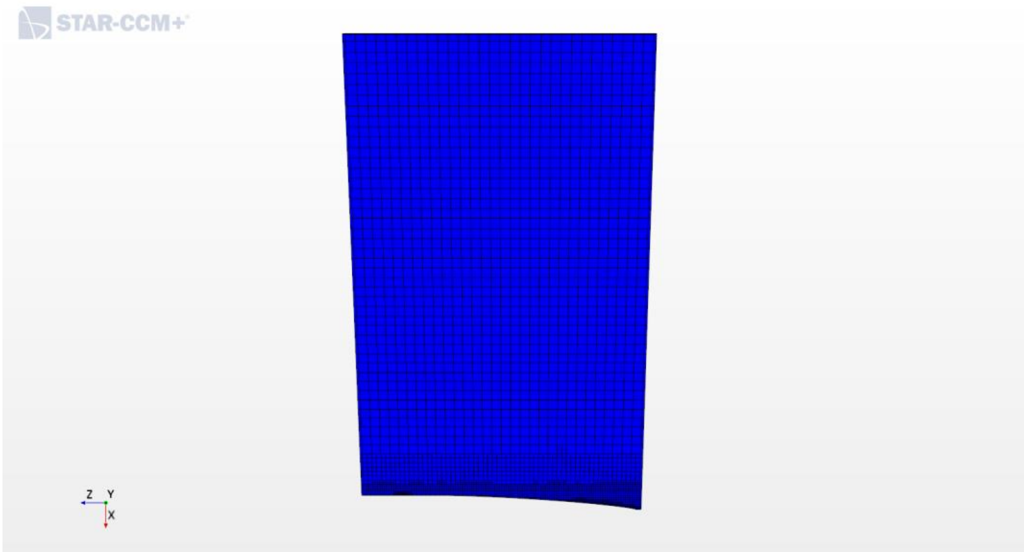

Figure 6: Fluid Region Mesh (same for all simulations)

Figures 7 & 8 show the refined mesh areas for the camera module and the proposed concept cover, respectively.

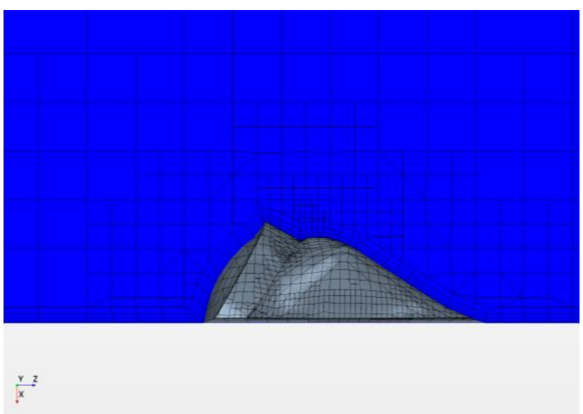

Figure 7: Refined Mesh Camera Module

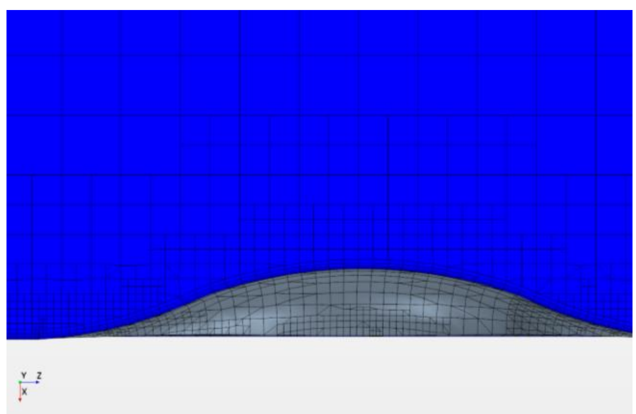

Figure 8: Refined Mesh Concept Cover

Results and Discussion

The following figures were generated from their respective simulations at 200m/s. The pressure plots shown in Figures 9, 10 & 11 show the stark difference in camera orientations and the improvements gained with the concept cover. The high pressure areas represent areas of large drag force, and the low pressure zones behind the features are indicative of eddy formation. The formation of eddies behind both camera orientations and streamline separation in the camera backward orientation are shown in Figures 12 & 13, respectively.

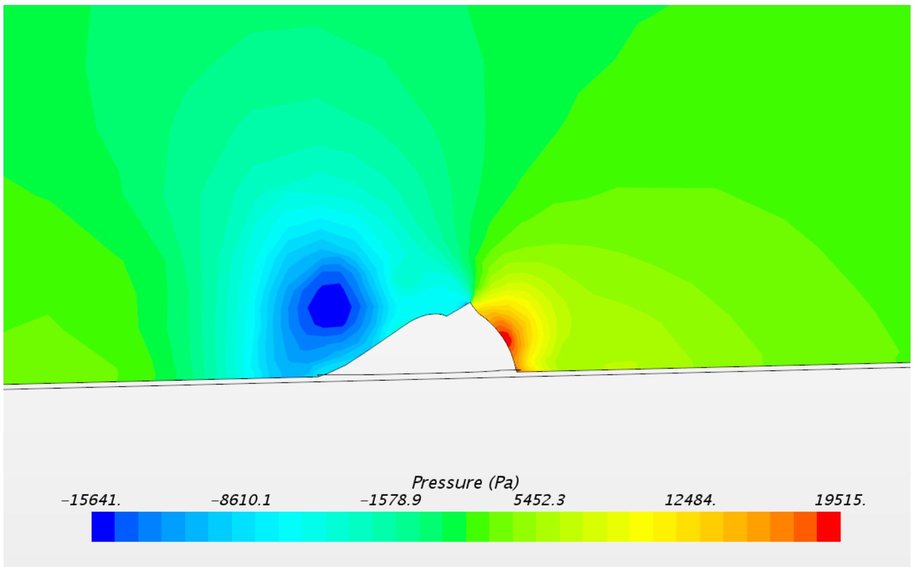

Figure 9: Pressure Map of Camera Forward Orientation

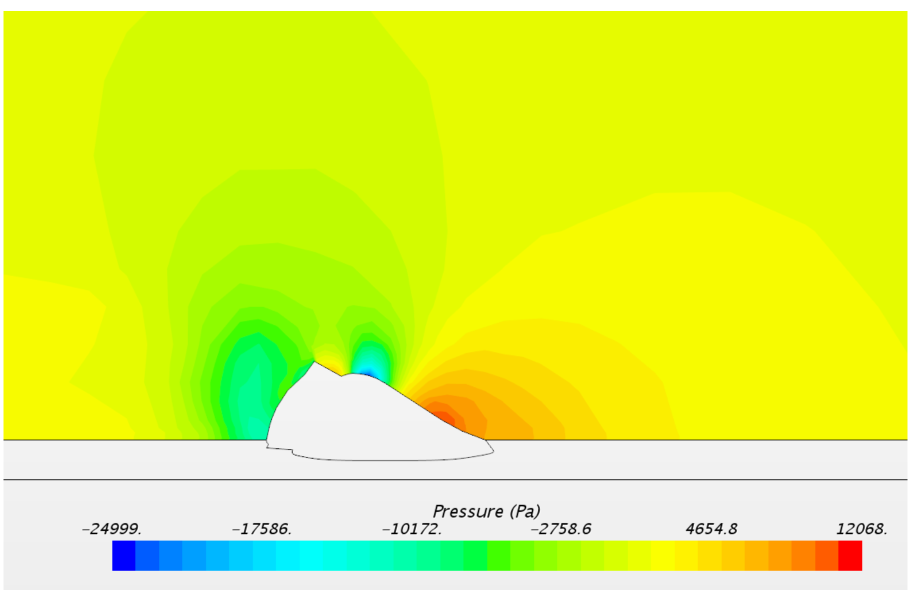

Figure 10: Pressure Map of Camera Backward Orientation

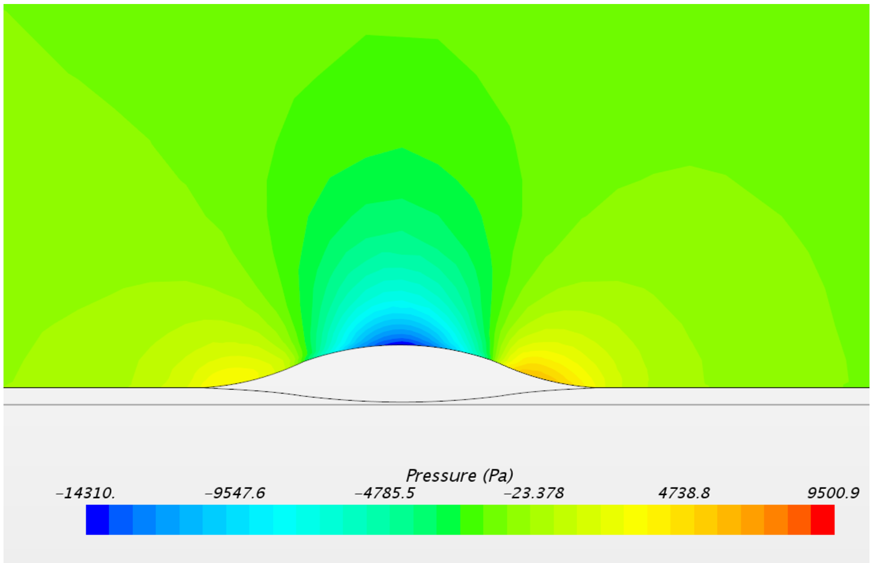

Figure 11: Pressure Map of Concept Cover

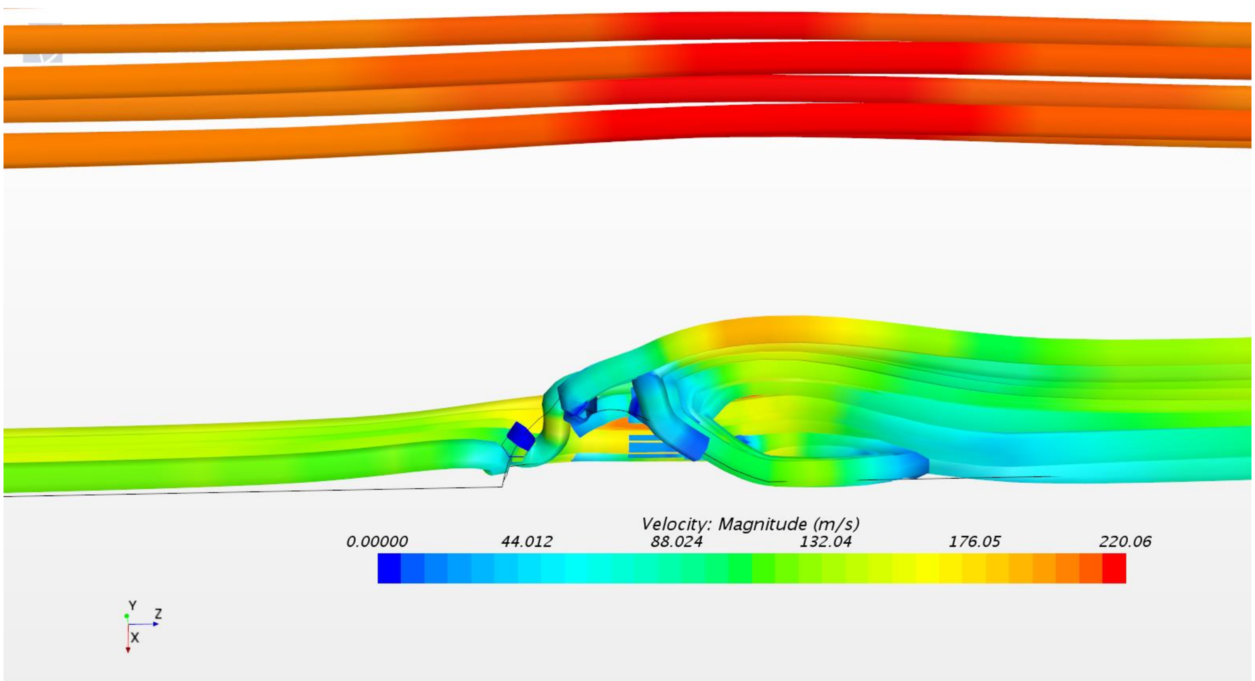

Figure 12: Streamlines over Camera Forward Orientation

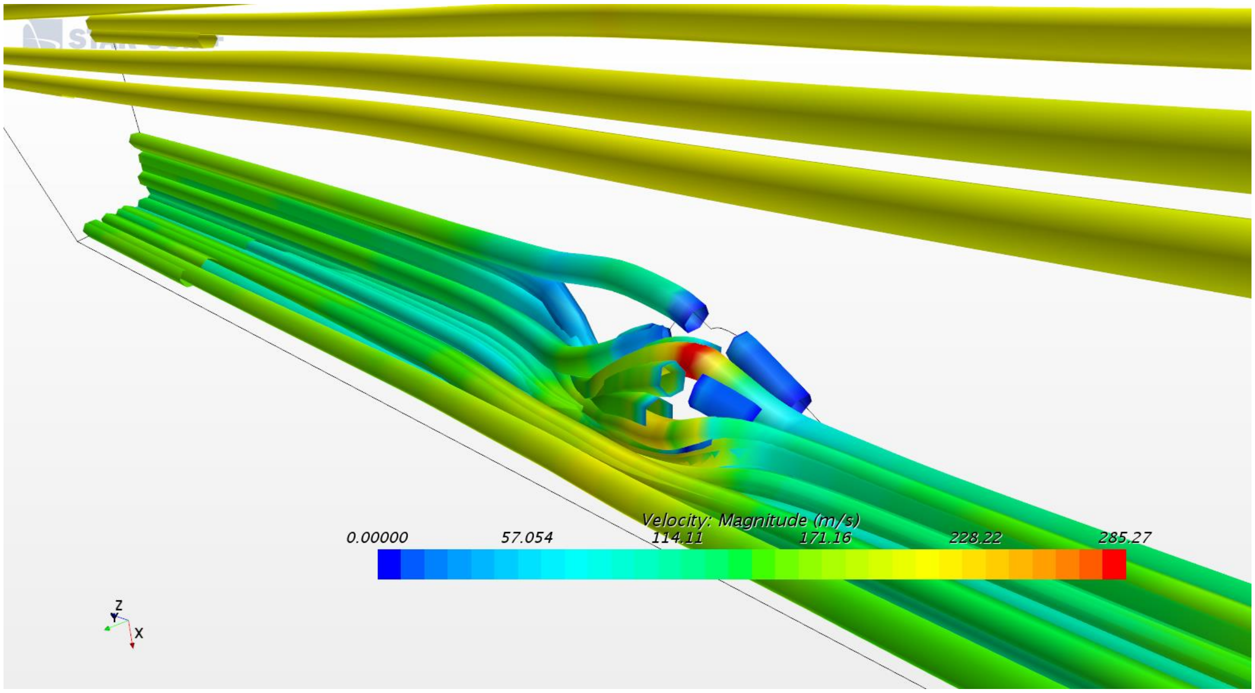

Figure 13: Streamlines over Camera Backward Orientation

By contrast, Figure 14 shows the smooth streamlines over the concept cover, which highlights the lower drag forces present and the lack of eddies or vortex shedding present in the other simulations.

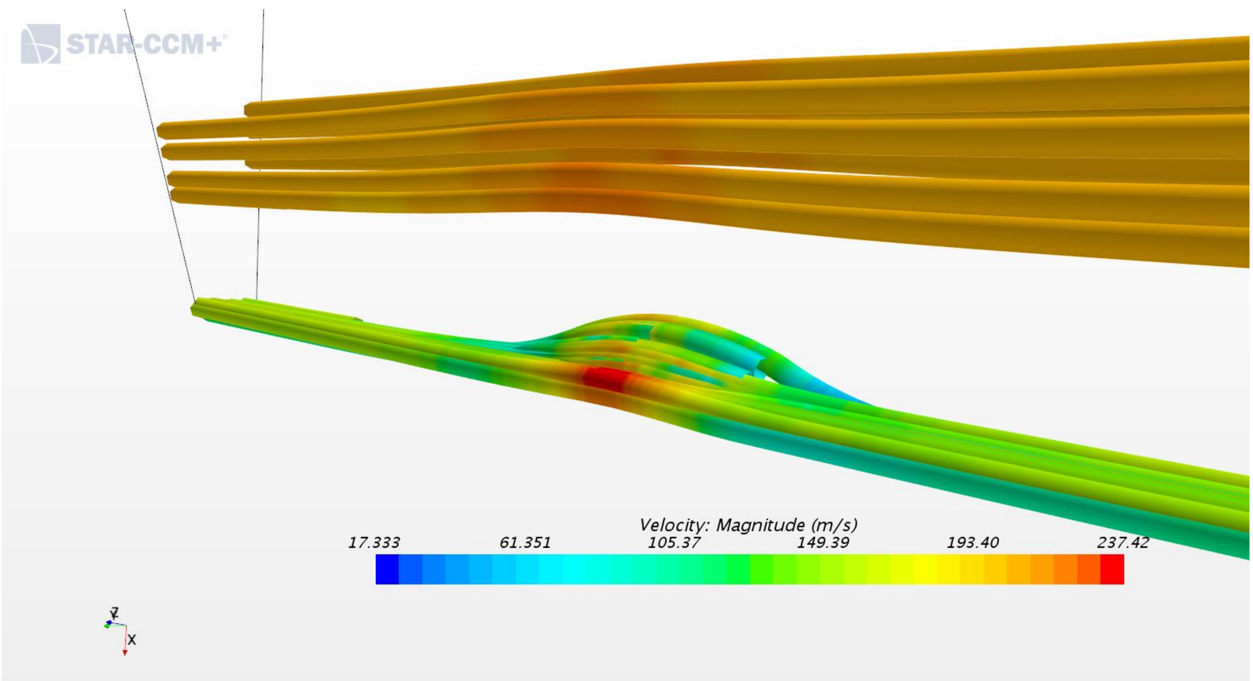

Figure 14: Streamlines over Concept Cover

Using the thrust (3.5kN) and burn time (6.16s) data from Pro98's data sheets, which was used in the last LV3 launch, and the idealized equations of motion to calculate the total theoretical altitude of the rocket from Hardin's article on rocket kinematics, and the drag coefficients generated by the STAR CCM+ simulations, the values in Table 2 were calculated. The velocities shown are a product of the drag force, and used to calculate the total altitude. The ideal case listed below matches the actual altitude reached by LV3.

Table 2: Drag Coefficients, Drag Force, and Total Theoretical Altitude

	Cd	Velocity(m/s)	Weight(N)	Fd (N)	Total Altitude (m)
Ideal	0.00	299.96	256.27	0.00	5514.60
Camera Up	0.33	260.94	256.27	35.06	4277.78
Camera Down	0.18	277.75	256.27	18.85	4791.41
Both Orientations	0.25	269.35	256.27	26.95	4534.60
Concept Cover	0.05	293.09	256.27	5.55	5285.43

As shown in the table, there is a significant impact on the maximum altitude the rocket can achieve based on the additional drag. With the camera module in its current state, the idealize case shows a reduction in altitude of ~1000m. However, this is an idealized case, and it should be noted that the drag coefficients were calculated at 200m/s rather than the 300m/s that would satisfy the original average velocity. The decision to do so is reasonable given the linear, near constant drag coefficient values seen in Figure 15. More refinement is needed in the models to accurately represent this case, but given that there is a significant impact at 200m/s, some change to the geometry of the camera ring is warranted to improve the aerodynamic efficiencies of future launch vehicles.

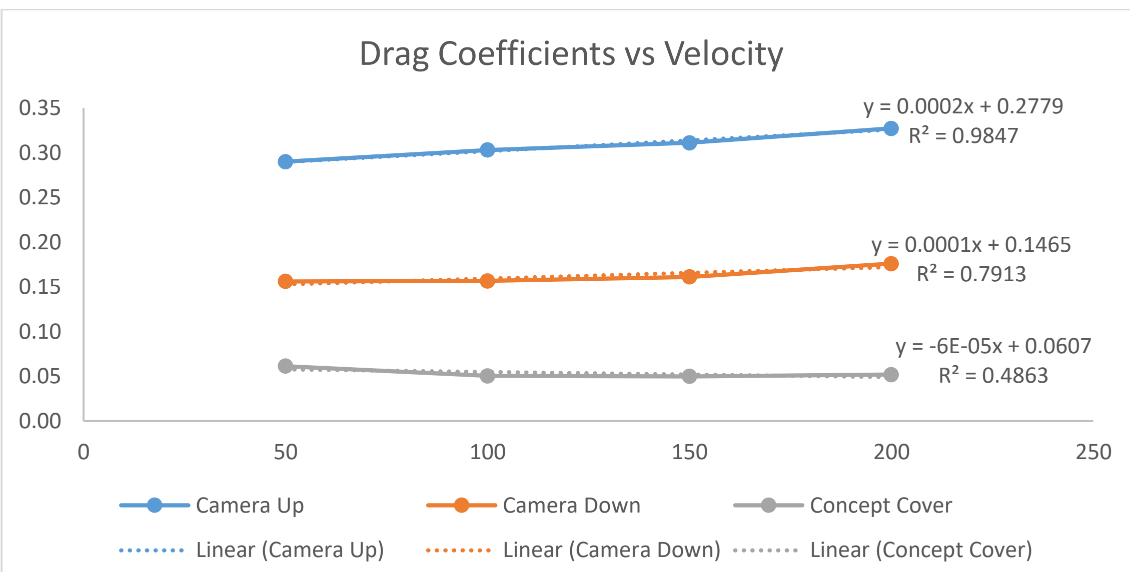

Figure 15: Plot of Cd vs Velocity over multiple runs of all simulations

The convergence plots of each simulation run at 200m/s are shown below. They show convergence after roughly 50 iterations, except for the concept simulation which was set to converge when continuity reached a delta of 1.0e-5, instead of 1.0e-4. The plots converge in 30s-1min (computing power dependent).

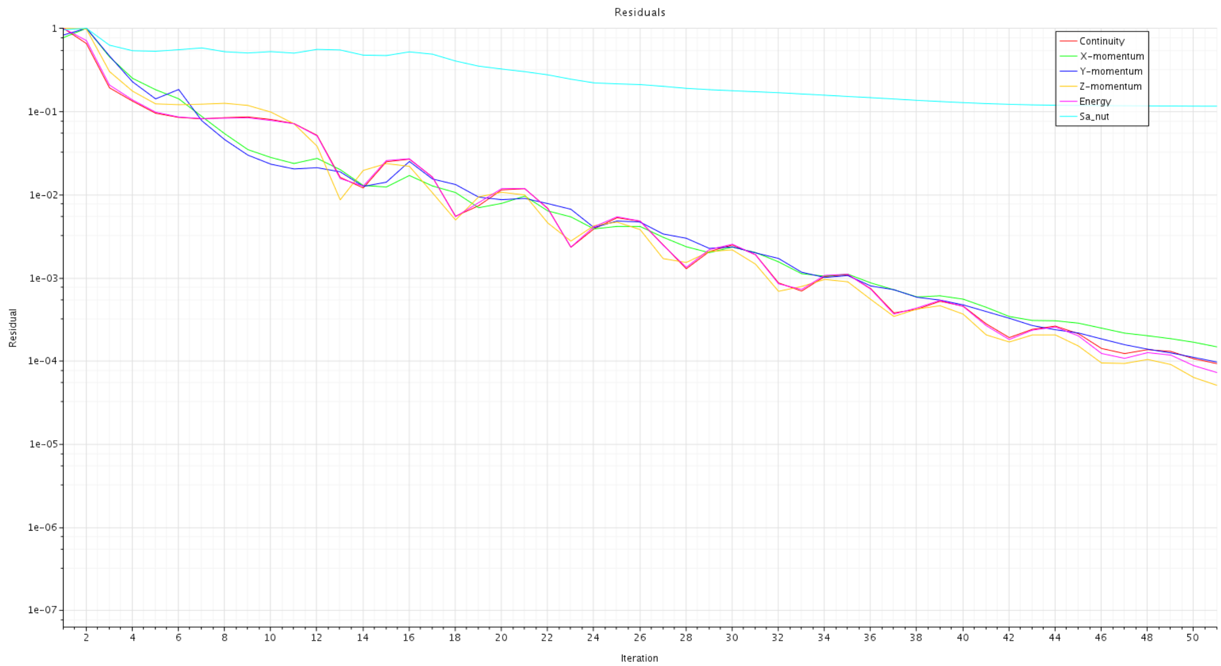

Figure 16: Residuals for Camera Forward Simulation

Figure 17: Residuals for Camera Forward Simulation

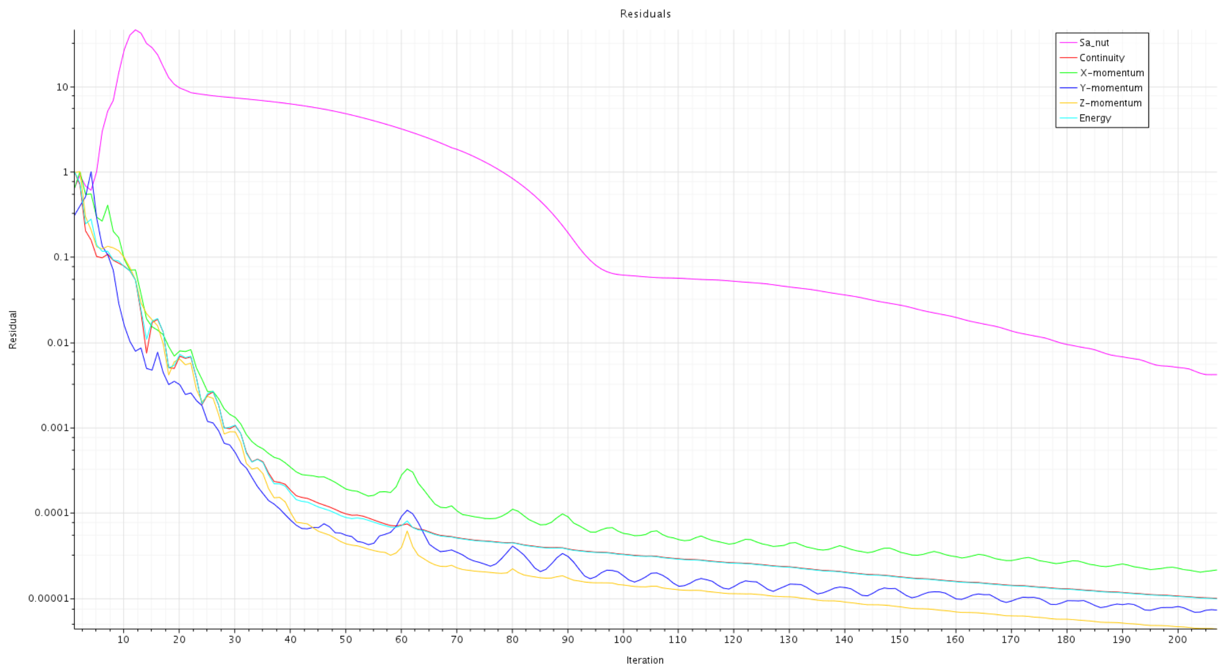

Figure 18: Residuals for Concept Cover Simulation

Conclusion

As demonstrated by the results in Table 2, and the visual indications of Figures 12, 13, & 14, the reduced drag produced by the concept cover is worth pursuing for PSAS' future launch vehicles. Gaining an additional 1000m is no small feat as the organization sets its sights on reaching the Von Karman line at 100km. The conceptual cover could be made from polycarbonate or another transparent material to allow the cameras vision while creating a more aerodynamic profile. The ideal solution would be to completely encase the cameras within a uniform transparent ring, which would have to maintain a similar compressive strength to the aluminum modules. This warrants further exploration, and corrective measures may need to be taken to account for the refractive index of the material in order to not distort the field of view of the cameras.

Further expansion of these simulations can also be done to explore larger velocities, and an investigation into whether or not these features create shockwaves before the nose cone is worth pursuing as long as the current module ring remains a payload on current launch vehicles.

References

Hardin, S. (2012). How High and Fast? The Equations of Motion. *Peak of Flight Newsletter*,(320), 1-6. Retrieved March 18, 2019, from https://www.apogeerockets.com/education/downloads/Newsletter320.pdf.

Pro98 21062O3400-P. (n.d.). Retrieved March 18, 2019, from http://www.pro38.com/products/pro98/motor/MotorData.php?prodid=21062O3400-P