Drag of Launch Lugs, Rail Buttons, and Launch Guides

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Summary

In this project, various configurations of launch lugs, rail buttons, and rail guides were simulated in the "Flow Design" software in an attempt to better understand the relative drag forces created by these objects on a model rocket. The Flow Design software is a virtual computational fluid dynamics (CFD) wind tunnel.

It was found that the software was not able to directly compute the drag of the objects because they were so small. To get around this issue, they were upscaled 10 times their original size so the drag could be estimated.

If the CFD results of upscaled versions could be correlated to the original size items, it was found that many long-standing assumptions about the drag of a launch lug were wrong. For example, one assumption modelers have about launch lugs is that shorter is better (lower drag). The CFD results showed the exact opposite, where short lugs are higher in drag, and a longer lug is better.

It was also found that sweeping both the leading edge as well as the trailing edge provided a smaller drag force than the typical squared off tube. By far the most important contribution to the drag of the launch lug is the shape of the leading edge. Just chamfering (or rounding off) the front edge of the launch lug with some sandpaper reduced the drag significantly. However, the back edge should not be altered, as rounding it off increases the drag contribution of the launch lug. It was also found that adding a glue fillet to the launch lug lowered the drag, which was expected.

The Objectives of the Work

The objection of this project was to generate some drag numbers for launch lugs, rail buttons, and rail guides. The desired outcome that I want to achieve is to generate a procedure for other modelers to use when they run computer simulations to determine the performance of their rockets.

Background

Before we can improve on the current simulation software, we need to know more information about the rocket. I am asked all the time by RockSim (https://www.apogeerockets.com/Rocket_Software/RockSim) users how the drag of a rail button compares to a launch lug. When RockSim was first developed and written, rail buttons and rail guides were not used, even for high power rocketry. At the time, even high power rockets were launched from large diameter launch rods.

Unfortunately, no one has undertaken a research project to find out how much drag these components add to a rocket. Indeed, the drag of a launch lug isn't fully understood. One noted reference to launch lug drag I found says:

"In conclusion, however, I must reiterate that the prediction of drag due to launch lugs remains at the time of write almost a matter of empirical art -- *of "guesstimating".* - Mandell, Caporaso, Bengen.

The Approach Taken

The method taken to find the drag of these items was to run Computational Fluid Dynamic simulations of air flowing past the items. The software used for this task was "Flow Design" by Autodesk. (http://www.autodesk.com/products/flow-design/overview)

> *"Flow Design is a virtual wind tunnel for visualizing airflow around buildings, vehicles, buildings, consumer products, and other objects. Support for many CAD file types means that little geometry preparation is necessary. With rapid results, you can quickly gain insight while exploring different conditions."* - AutoDesk Website

The one question that I cannot answer is: "how accurate is the Flow Design software?"

That is the one question that runs through any aerodynamicists mind about any CFD simulation. Results eventually have to be verified with wind tunnel testing or other real-world experiments. That was beyond the scope of this project. What I wanted from this was some ballpark estimates that could be used to put rocket simulations into perspective.

The Flow Design software can be downloaded at: http://help.autodesk.com/view/ADSKFD/ENU/?guid=GUID-1BC66744-4088-41F4-B6BB-8B4BA0B09FF9. Autodesk has an educational policy that lets schools use this particular software for free. A nice addition to this policy is that if you mentor a student, you can also use the software for free. Since I mentor Team America Rocketry Championship (TARC) students, I took advantage of the free license to use the software. Incidentally, I originally found out about the software because a TARC team came to me with results from the Flow Design software and asked me to interpret the results for them.

Flow Design is not AutoDesk's premier CFD simulation software. That honor goes to AutoDesk CFD (http://www.autodesk.com/products/cfd/overview). The unfortunate thing is that the license to use AutoDesk CFD costs $7,000 per year, and they don't have a free educational version that I know of.

The one negative caveat about CFD software, is that in order to use it, you have to input a 3D model of the item you want to immerse in the virtual wind tunnel. Fortunately, Flow Design imports the .stl file formats, which is the same format used by 3D printers. So most any Computer Aided Design (CAD) software can be used to generate the models. I personally use another Autodesk CAD product called "Fusion 360" (https://knowledge.autodesk.com/support/fusion-360). But most any CAD program can be used to create the models.

Therefore, the first step of this project was to create the 3D models of the various items (launch lugs, rail buttons, and rail guides) in the CAD software. Each specific item took between 15 to 30 minutes to generate before they could be imported into the Flow Design CFD software.

The one problem I discovered right away when using the CFD software is that model rockets are relatively small compared with the typical things used in wind tunnels (like cars and full-size aircraft). With small items, the aerodynamic forces generated by them when in the wind tunnel are very tiny (forces in the thousands of a pound). I verified this by running a simulation of the Apogee Avion rocket (https://www.apogeerockets.com/Rocket-Kits/Skill-Level-1-Model-Rocket-Kits/Avion) which is about 15 inches long, with and without a standard 1/8" diameter X 1" long launch lug attached.

The results of those two simulations were that the computed C_d and the drag force were identical. In other words, the Flow Design software couldn't discern the difference between the drag with or without the launch lug added to the model rocket.

To repeat, the rocket and the launch lug were just too small to generate sufficient forces that could be computed. Therefore, I used a common tactic that is used in aerodynamics for just this situation: make the models larger so that the forces would also be magnified.

For all the simulations, the models were 10 times larger than their real life size. So a 1/8" launch lug (https://www.apogeerockets.com/Building_Supplies/Launch_Lugs_Rail_Buttons/Launch_Lugs/1_8_Launch_Lug), which has an outside diameter of 0.162 inches, would be 1.62 inches in diameter in the CFD simulation.

The main problem with changing the size of the model is that it also changes the Reynolds number of the flow {the Reynolds number is dimensionless and describes the ratio of inertial forces to viscous forces in a flowing fluid. It is used in many fluid flow correlations and is used to describe the boundaries of fluid flow regimes (laminar, transitional and turbulent).}

In real life, the small components (i.e.. launch lugs) would be in the very low Reynolds number regime - typically laminar flow only). By making them 10 times larger for the simulations, it is possible to generate errors because the equations might have switched from laminar to turbulent flow. For example, surface finish become more important, and the software doesn't have any input for roughness, so I had to assume that it assumed a very smooth finish.

Because of this, I wasn't expecting to be able to use the exact drag coefficients it generated. I was looking for was changes in magnitude. Therefore, I used as a comparison the 1/8" diameter launch lug as my baseline for which everything was compared against.

For example, when running the complete Apogee Avion model in the CFD simulation, the drag changed from 9.382 lbs without the launch lug, to 10.907 lbs with it. Therefore, I could say that the lug added 16.3% more drag to the rocket.

Incidentally, 16.3% is quite significant, which is why if you want to fly for maximum altitude, you should always attempt to remove the launch lug from the rocket.

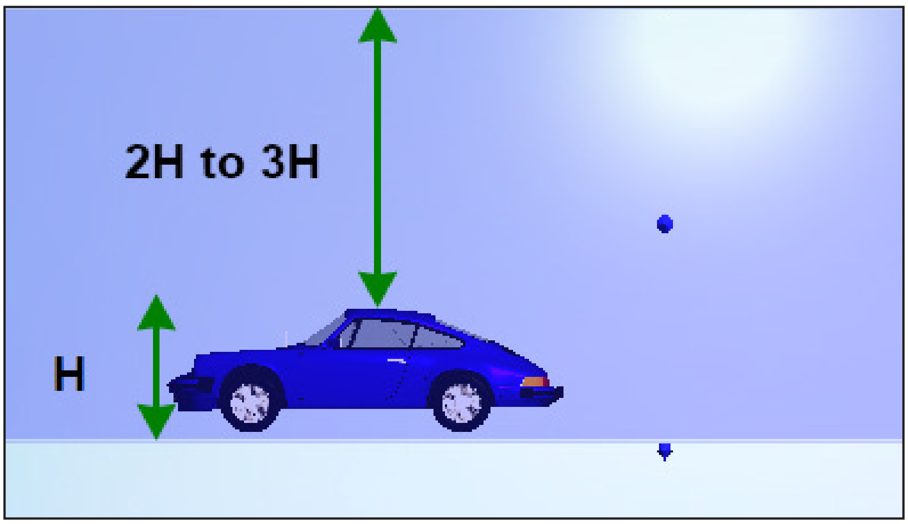
The next step was to isolate the launch lug from the rocket and find the drag and C_d of it by itself.

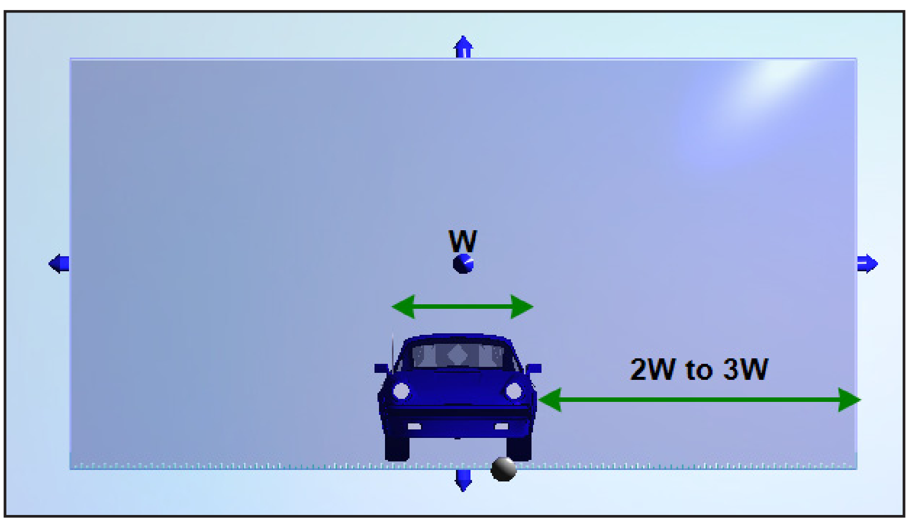
To be honest, my first attempt at doing this was a mistake. I used the default speed of 32 feet/sec, and only latter did I figure out that I had the wind speed too slow. The mistake was operator error because I was not familiar with the software.

While the Flow Design software is easy to use, there is a little bit of a learning curve that you have to go through. You have to configure model and the wind tunnel correctly. The AutoDesk web site recommends these parameters as a minimum:

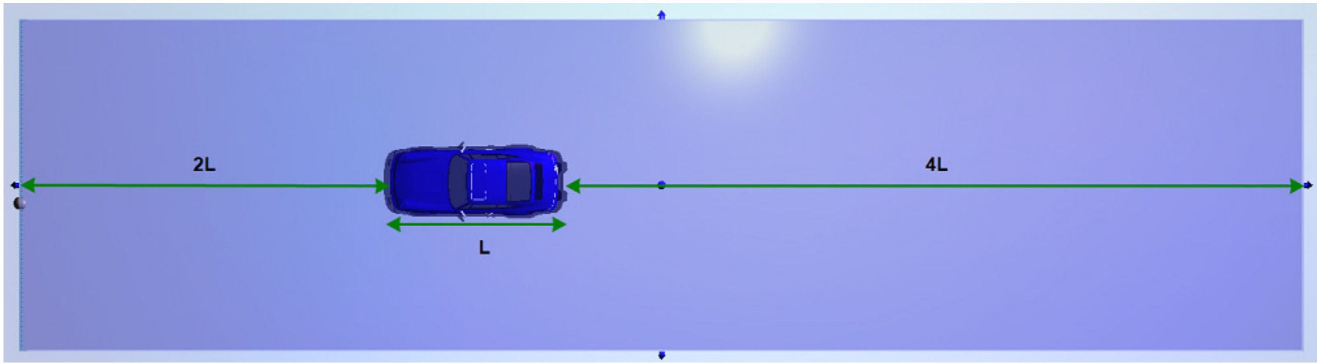
Guidelines for Wind Tunnel Size

For best results, the gap between the wind tunnel and the model should be two to three times the dimension of the model in that respective dimension:





The wind tunnel should also be adequately sized in the direction of flow. Ideally, the wind tunnel should extend at least 2 model lengths upstream and at least 4 model lengths downstream. This distance ensures that the boundaries do not artificially affect the flow approaching the model, and allows correct formation of the wake downstream of the model:



You also have to adjust the wind speed and size the input the units that the model was originally generated in. I used inches, and the CFD software assumed it was mm. So my models were too small to generate sufficient forces. In addition, during my first attempts at running simulations, I didn't notice that the default speed of the airflow was low: 32 ft/sec. I wanted to run the simulations at a speed of a typical model rocket, which I estimated at 100 miles per hour. So I also had to convert that to feet/sec (146.667 ft/sec = 100 miles/hour).

When I finally figured out how to use the software correctly, the 1/8" diameter X 1" long launch lug (at 10X its actual size), had a C_d of 0.60 and generated a drag force of 0.051 lbs. This was the baseline condition to which everything else was compared.

A Note About C_d Values

The Flow Design software computes a Drag Coefficient (C_d) value for the object placed in the virtual wind tunnel. The "number" can be deceiving, and needs to be put into perspective.

The reason is that the C_d is usually computed last, after you've measured the actual drag force. The Drag force formula is:

Drag = $1/2\ \rho\ C_d\ S\ V^2$

Where:

ρ is the density of air

C_d is the drag Coefficient

S is some reference area

V is velocity of the air

In effect, the C_d is a "fudge factor" to make the equation work once you have measured the actual drag force. You measure the drag, and solve for C_d.

The big unknown is the reference area (S). In model rocketry, we use the cross section of the rocket's tube as the reference area. But when working with this software, I don't know what reference area it uses. It is arbitrary for each item placed in the airflow because each item has an arbitrary shape.

Therefore, we can't compare the C_d values of a drammatically differe shapes like a launch lug against a rail button, because they might be using different reference areas. To make a comparison, we have to look and compare the actual drag forces of the objects. As we'll see in the results section, the rail button has a higher drag force than a launch lug.

However, we should be able to compare the C_d values of two launch lugs, say a long one versus a shorter one. That should be an apples-to-apples comparison.

List of any related R & D Reports previously entered by the author, if any, with brief summaries

Development of the Fly-Away Rail Guides - By Tim Van Milligan. NARAM-52 R&D Report (2010). - Available at: https://www.apogeerockets.com/downloads/PDFs/Development_of_Rail_Guides.pdf

Brief Summary: This report is related because it showed the research and development that occurred to create a way to launch long or high-powered rockets without having to use launch lugs or rail buttons. It inspired Mayhem Rocketry to create 3D printed Fly-Away Rail Guides that it sells through Animal Motor Works. Video at: https://www.youtube.com/watch?v=h4lqfWXD0Sg

The Effectiveness of a Turbulator on Egglofting Rocket - By Tim Van Milligan. NARAM 31 R&D report. Available at: https://www.apogeerockets.com/downloads/PDFs/turbulator.pdf

Brief Summary - This report looked at the aerodynamics of a egg lofting rocket. It unfortunately was inconclusive. It is related to this project because this project might be repeated using the CFD software described in this new report.

References to previous work done on the subject, found in research preparatory to this report

Estes TR-11 Aerodynamic Drag of Model Rockets by Dr. Gerald M. Gregorek. 1970.

Topics in Advanced Model Rocketry by Gordon K. Mandell, George J. Caporaso, William P. Bengin. MIT Press, 1973.

The Equipment Used:

I used two different computer software applications:

Flow Design by Autodesk. (http://www.autodesk.com/products/flow-design/overview)

Fusion 360 (https://knowledge.autodesk.com/support/fusion-360)

The Facilities Used:

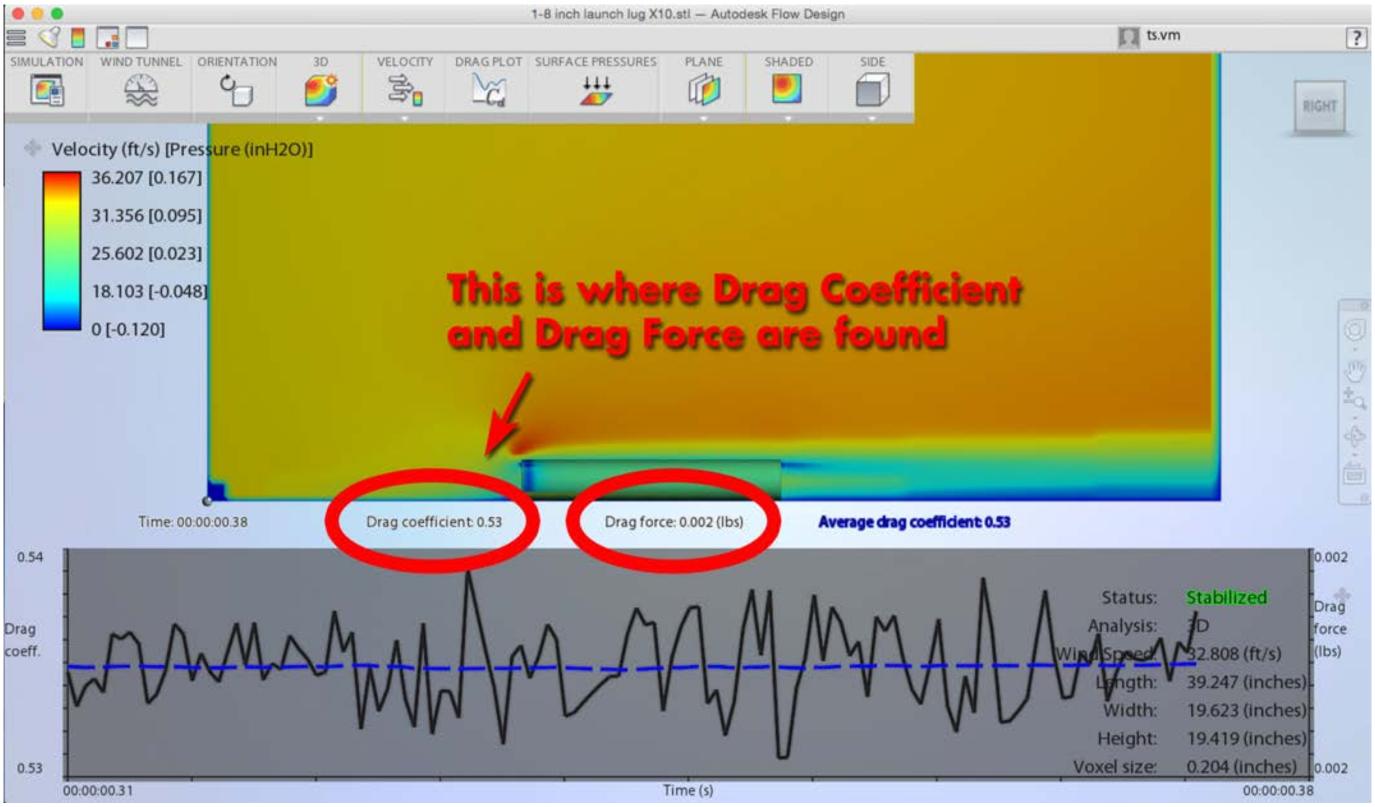
No special facilities were used.

The Money Spent On The Project (Budget)

No money was spent on this project, because the use of the software was free. There was however a huge investment of time. Each simulation took about 1/2 hour to set up, and then another 1/2 hour to complile.

The Data Collected

This is an example of the Flow Design software screen. From it, we'll get the Drag Coefficeint and the Drag force, which will be on the following pages for the various objects tested in the software.



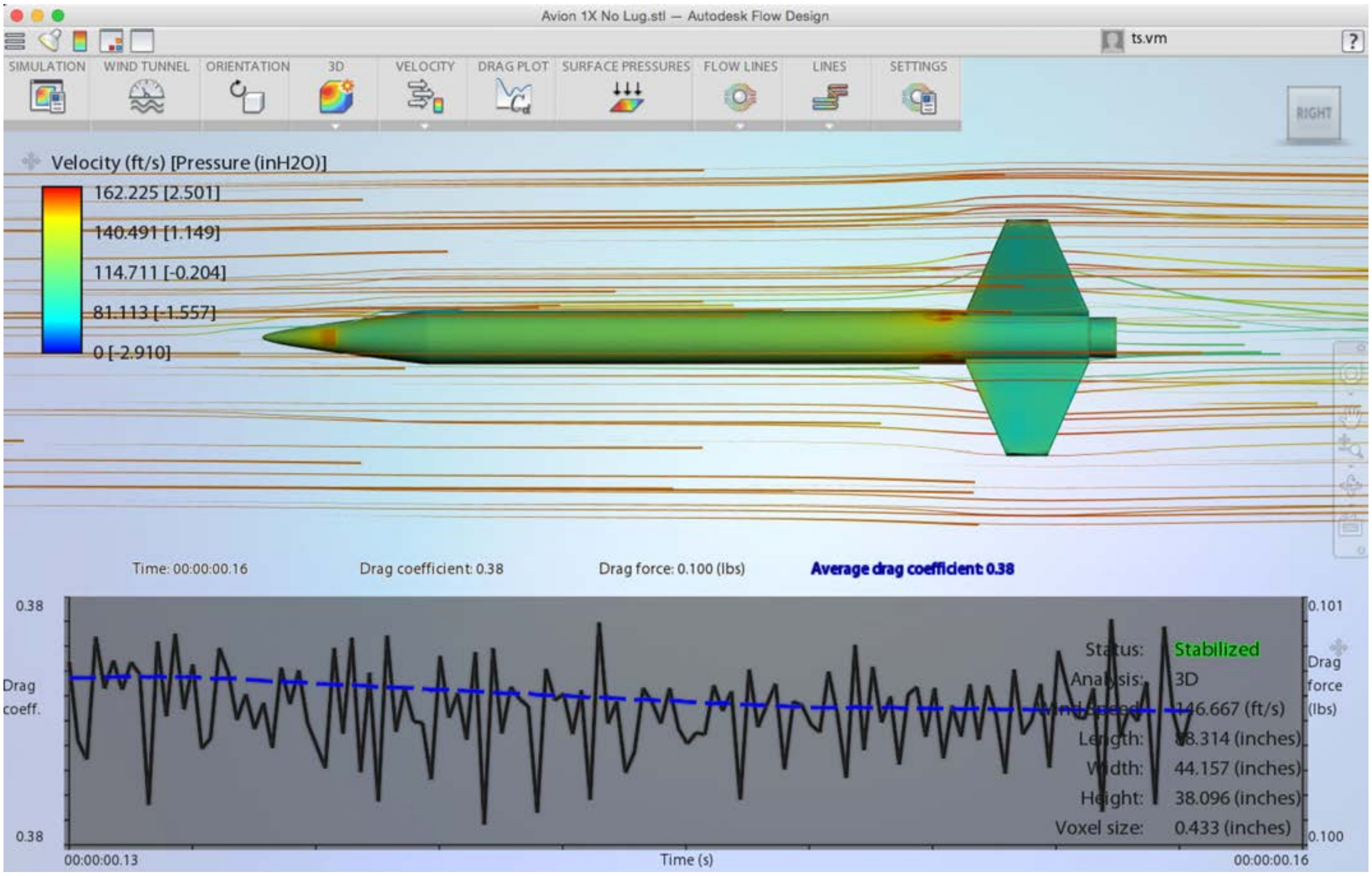
Example: Drag of 1/8" X 1" launch lug at 32.8 ft/sec air flow

The rest of the screen (also show here) gives other data too. The grey chart on the bottom scrolls while the results are being compiled. It typically levels out when the "status" (lower right) indicates that the airflow has "stabilized." It can take anywhere from 10 minutes to 1/2 hour to reach that point.

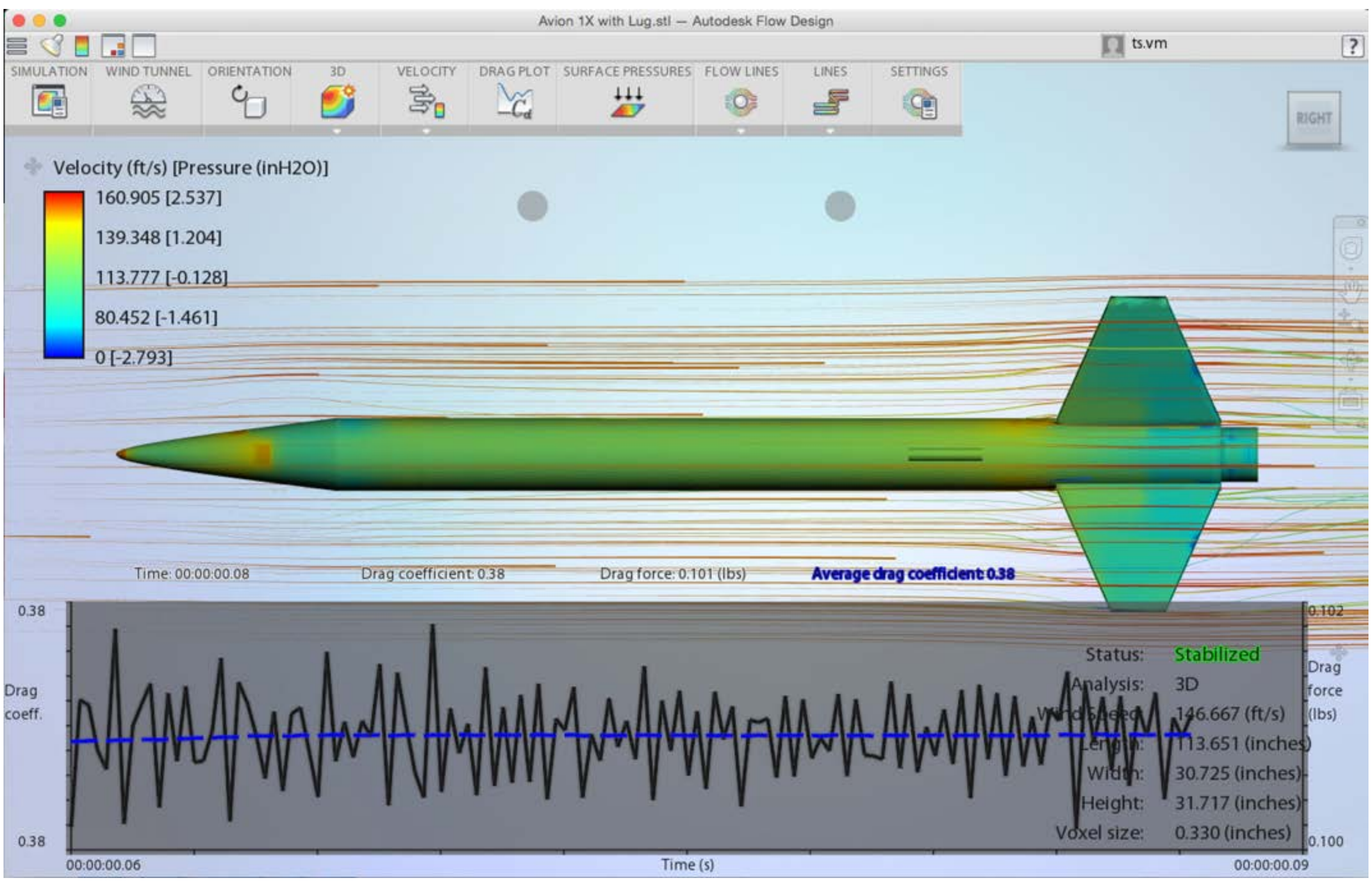
The image at the top shows (above the grey chart) can be set to show a variety of information. Here it is set to show the velocity of the air in the wind tunnel. This is the area that surrounds the model (which is positioned on the bottom of the tunnel). A blue color is used to show slow moving air, while a redish color is fast moving air.

Additionally, the color on the actual model shows other information - the surface pressure on the model. A bluish color here shows low pressure, and a red color would be a higher pressure. Pressure on a particular surface area creates a force. Summing up all the forces in the "X-direction" is what determines the drag force. Unfortunately, the "lift force" is not computed by the software, even though all the information is available. It is that the author of the program chose not to display it. They want you to upgrade to their other program...

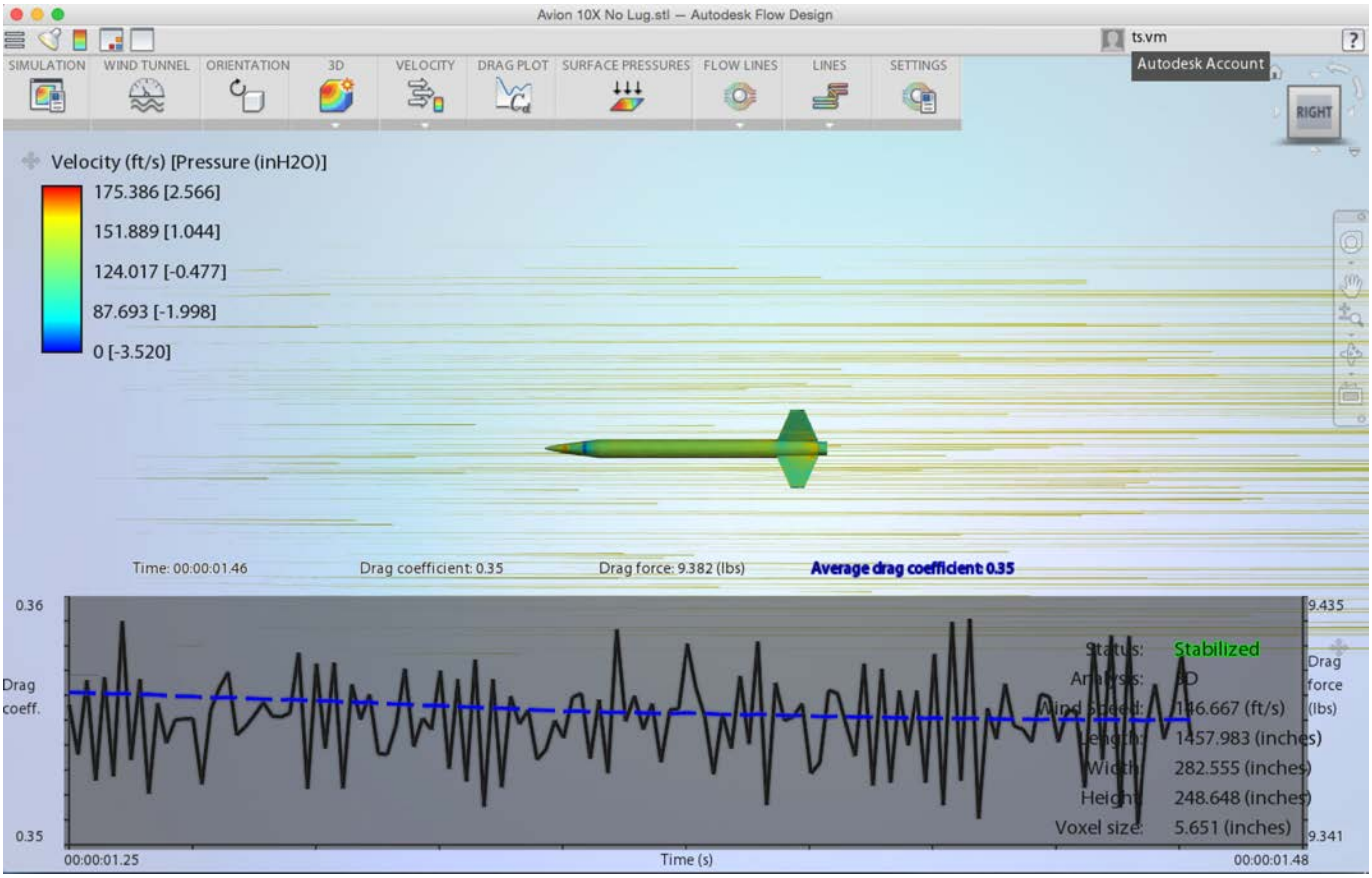
Other screens can be displayed too. Another useful screen is to see the individual movement of air particles over the object being test.



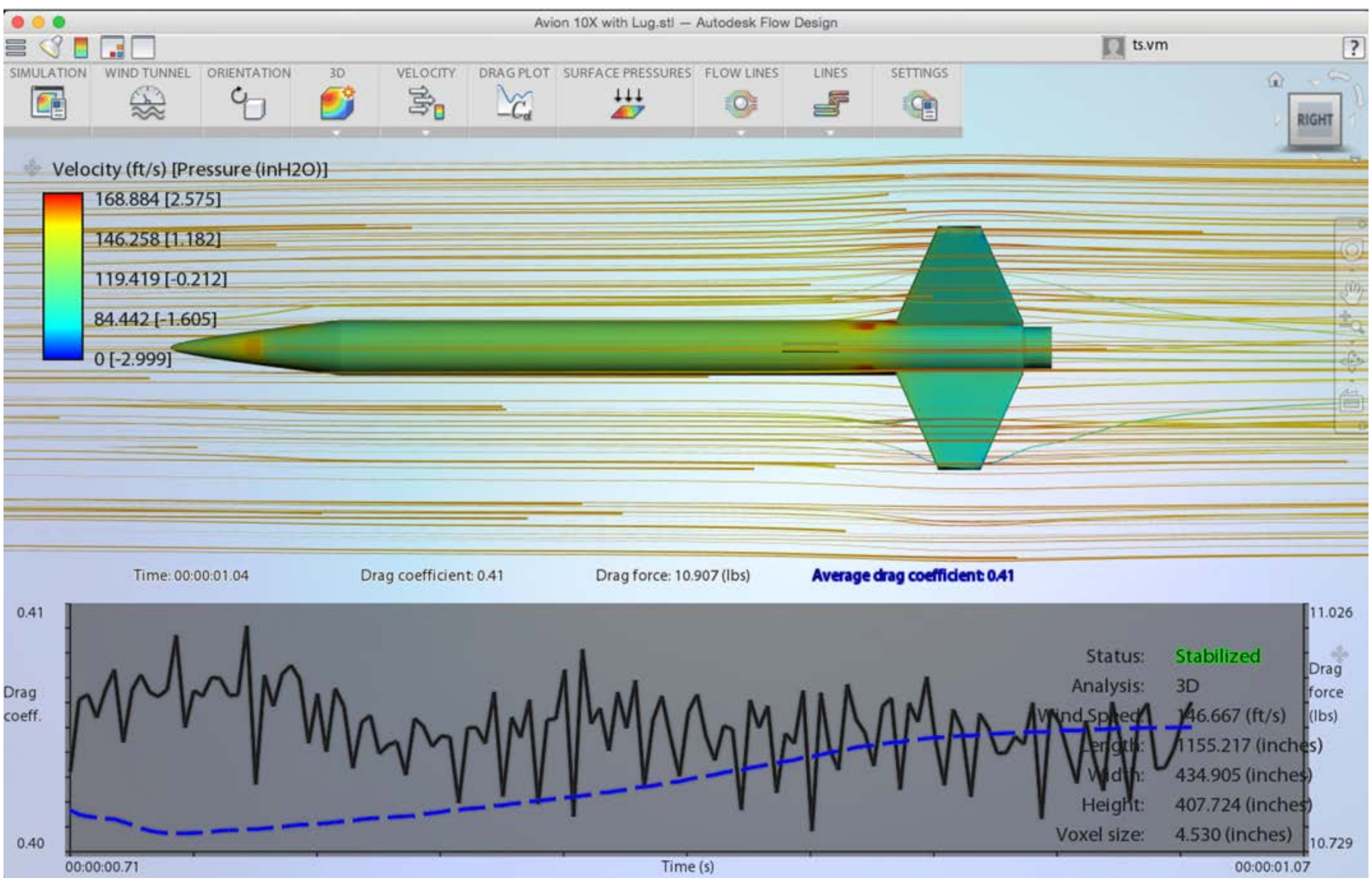
Simulation #1 - Apogee Components Avion rocket kit with no launch lug in 100mph air flow



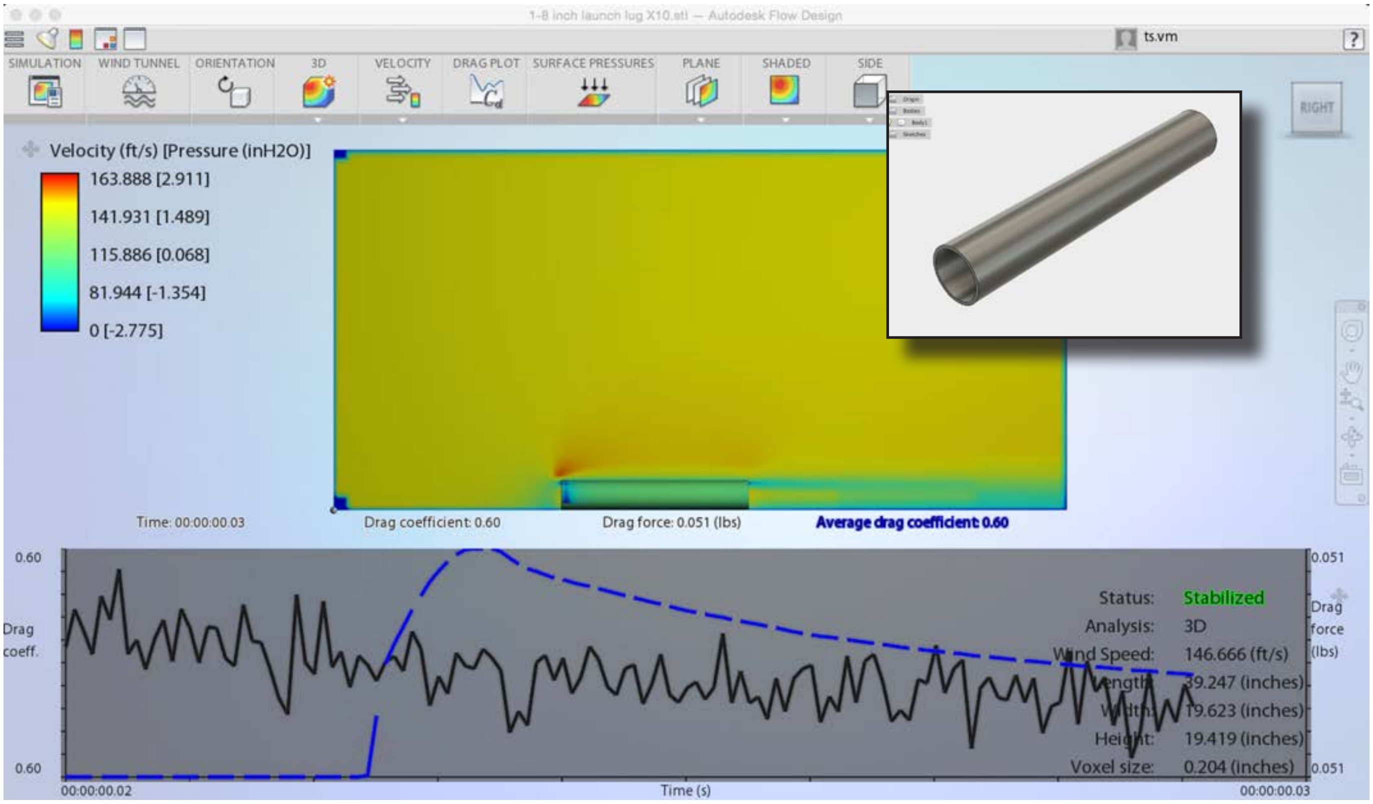
Sim #2 - Apogee Components Avion rocket kit with a launch lug in 100mph air flow



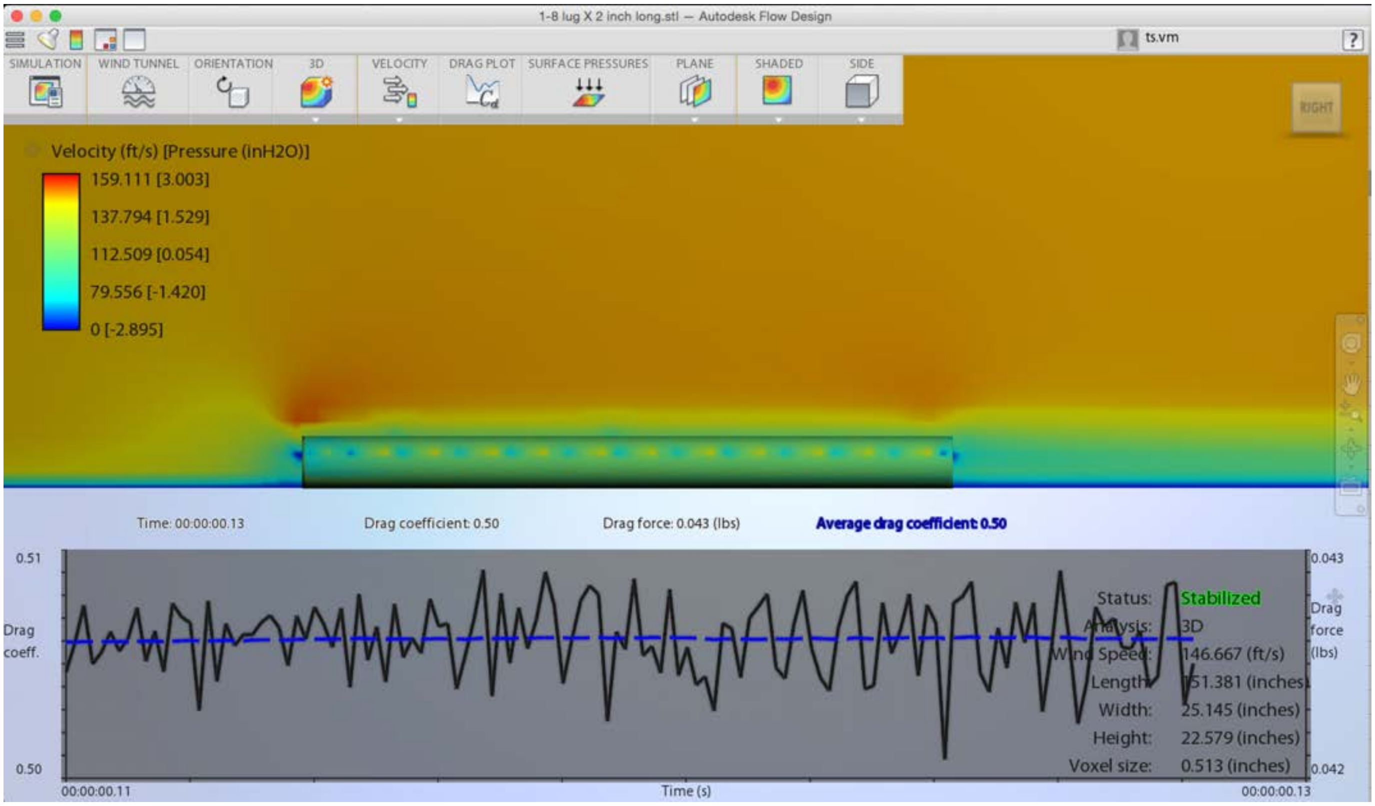
Sim #3 - Apogee Components Avion rocket kit (10X size) without launch lug in 100mph air flow



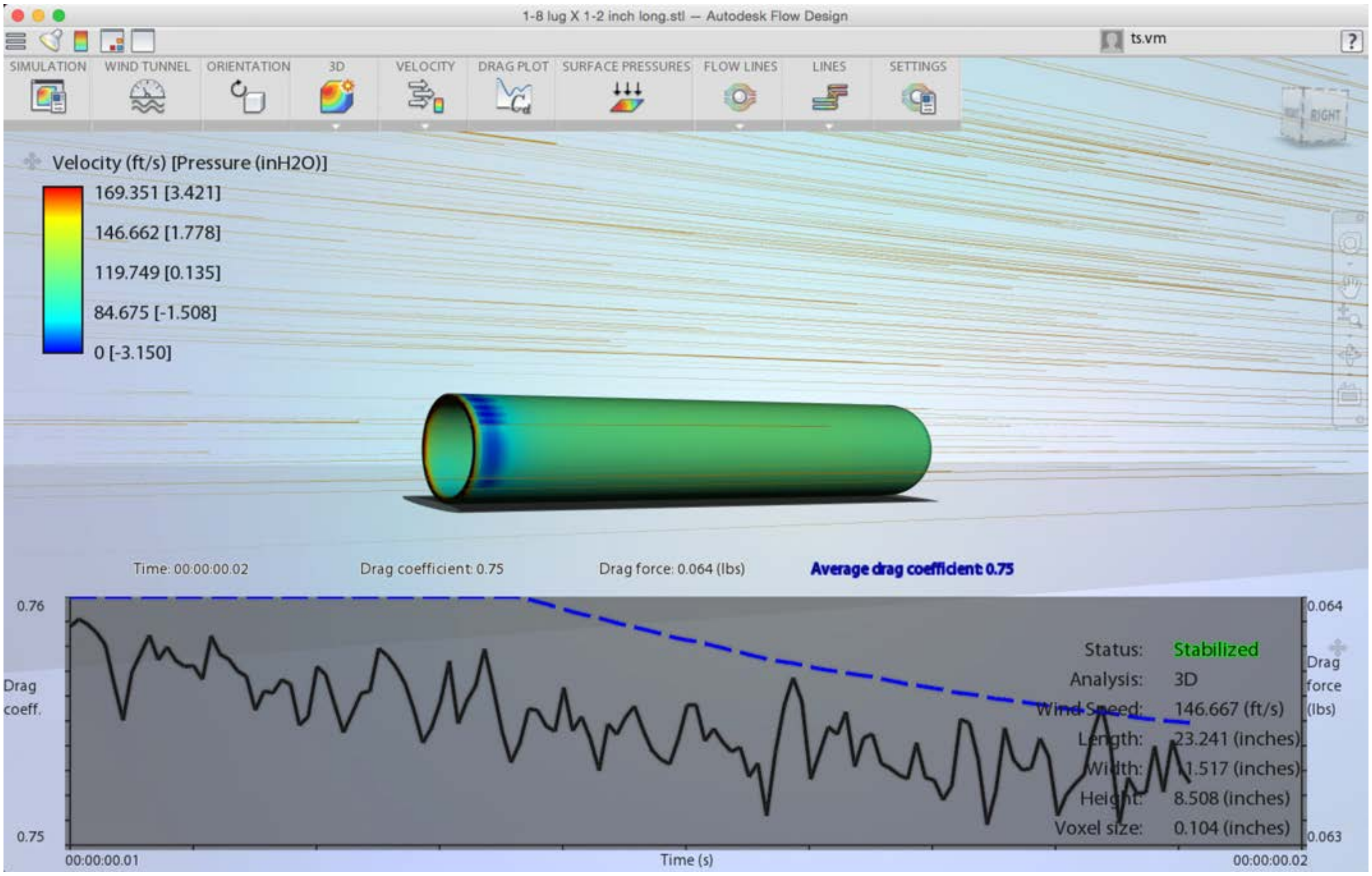
Sim #4 - Apogee Components Avion rocket kit (10X size) with a launch lug in 100mph air flow



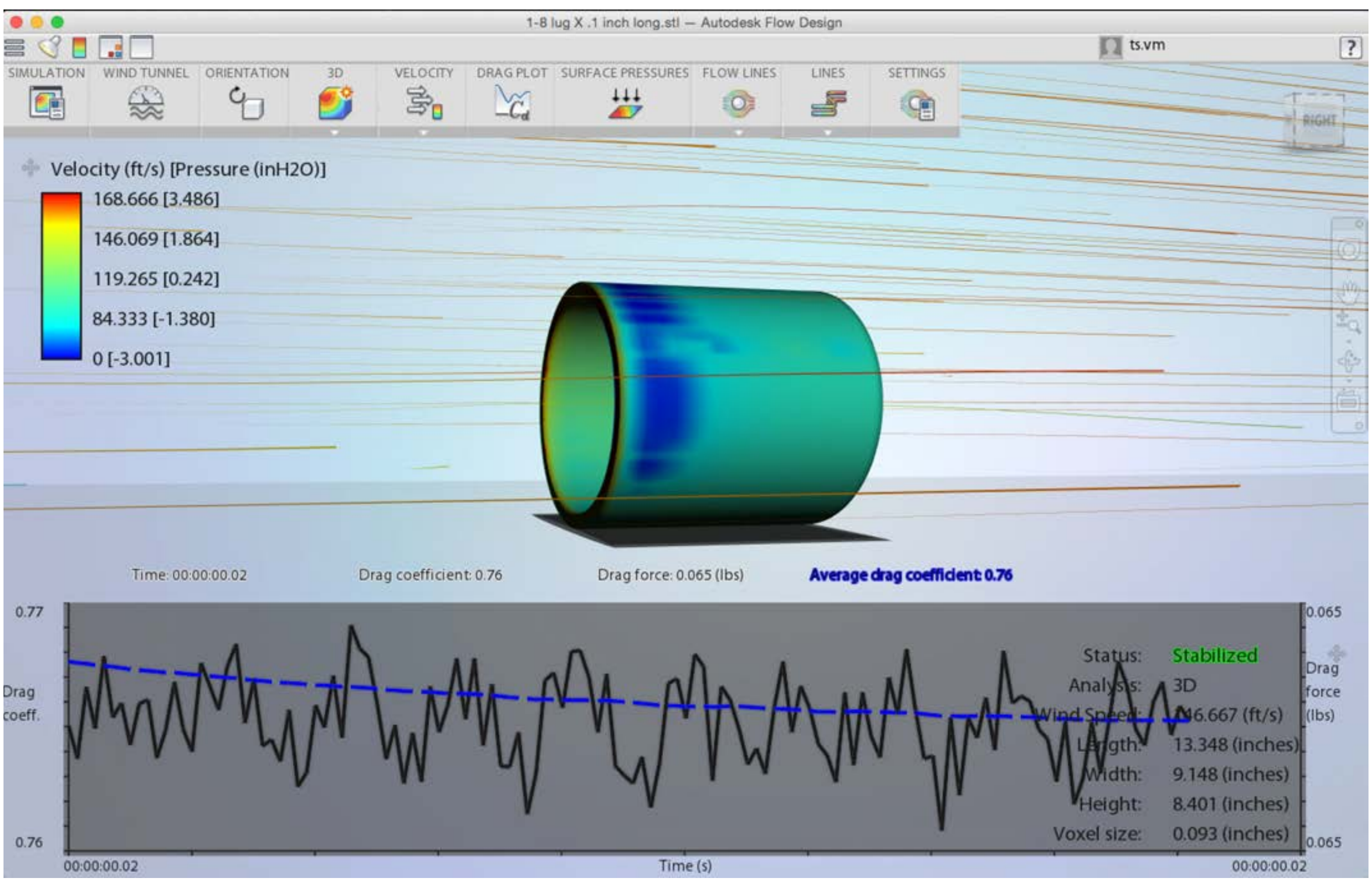
Sim #5 Drag of 1/8" diameter X 1" launch lug at 100 mph air flow. This is the baseline component.



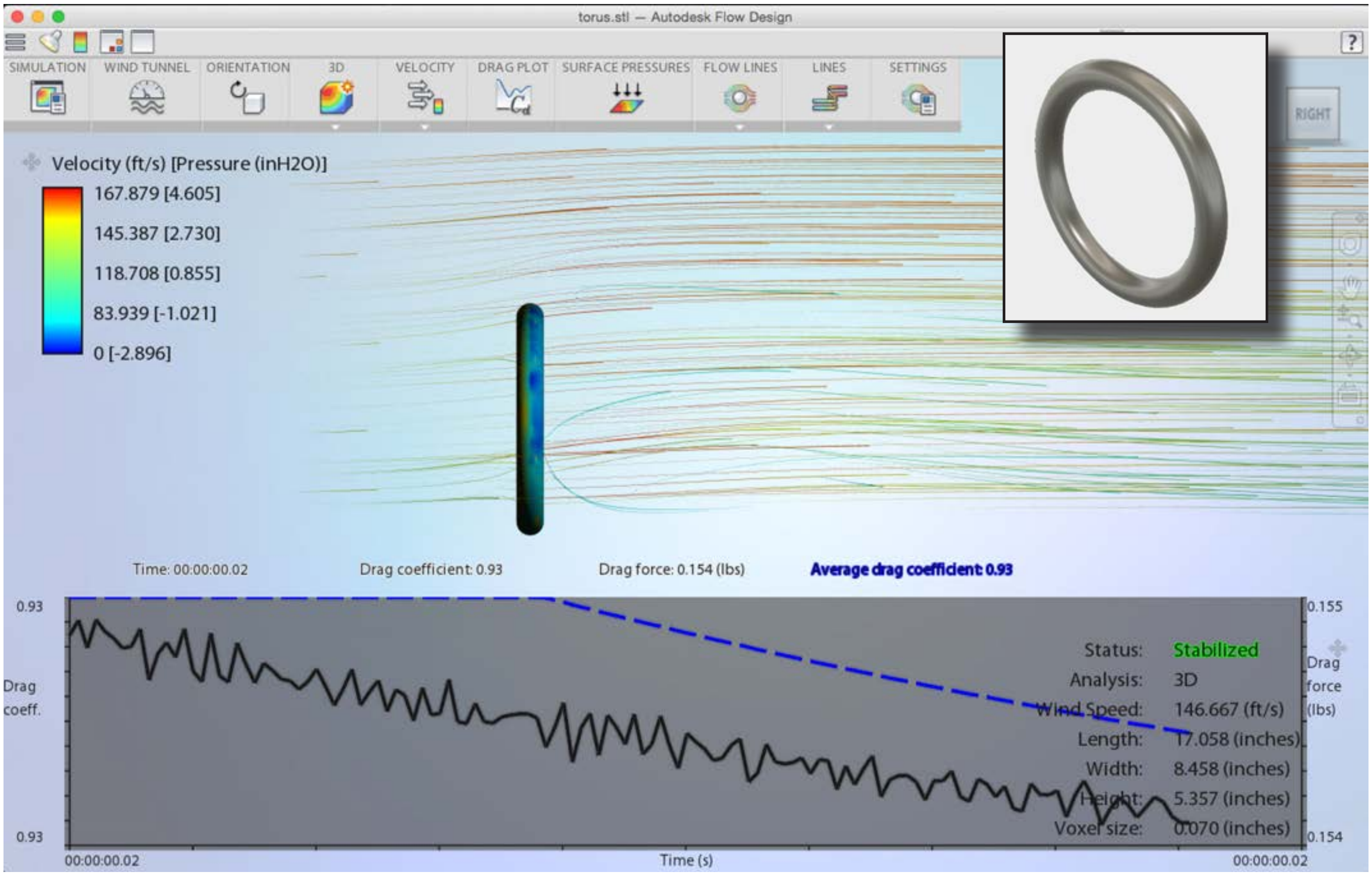
Sim #6 Drag of 1/8" X 2" long launch lug at 100 mph air flow. Note that the drag decreased from Sim #5.



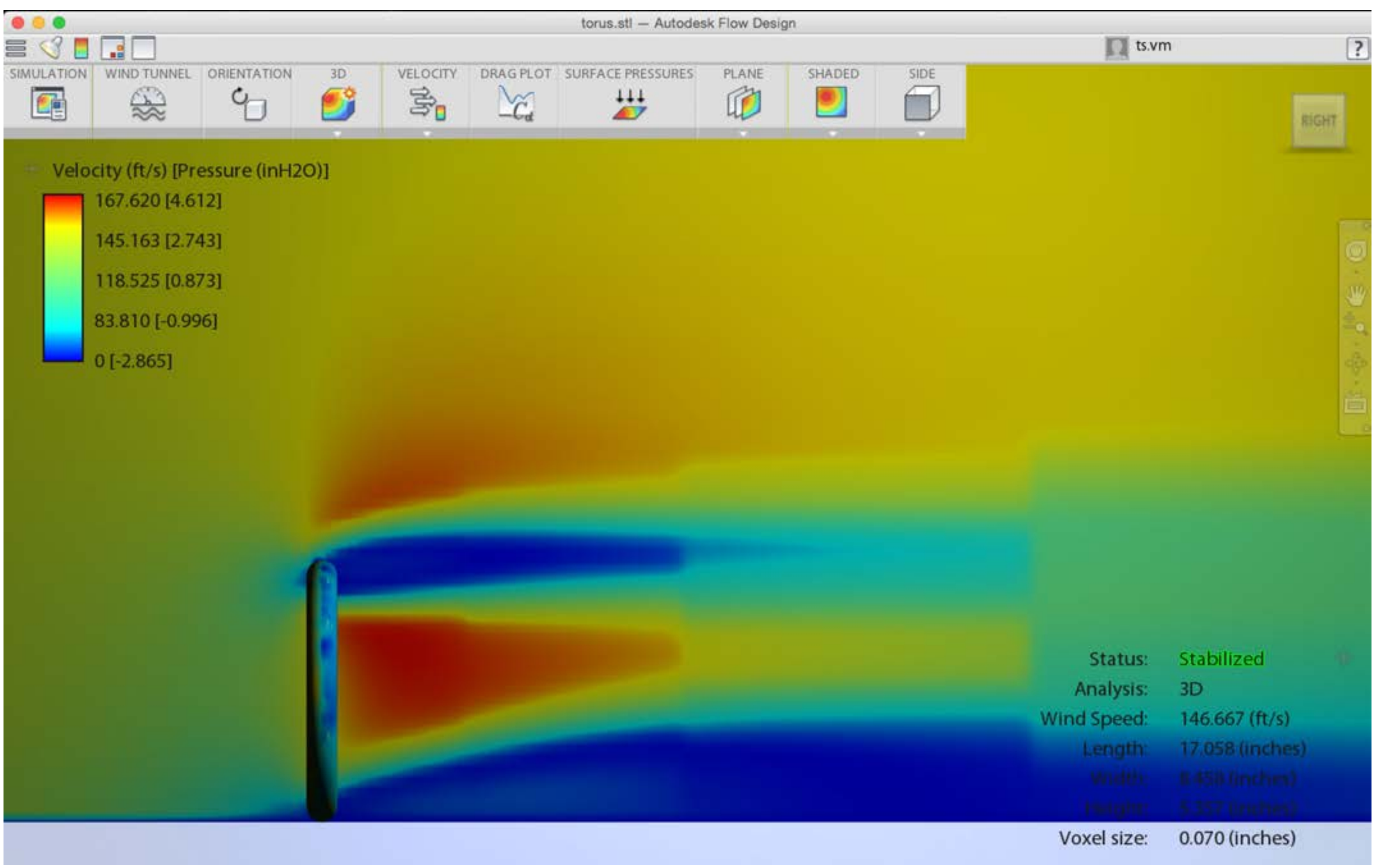
Sim #7 Drag of 1/8” X 1/2” long launch lug at 100 mph air flow



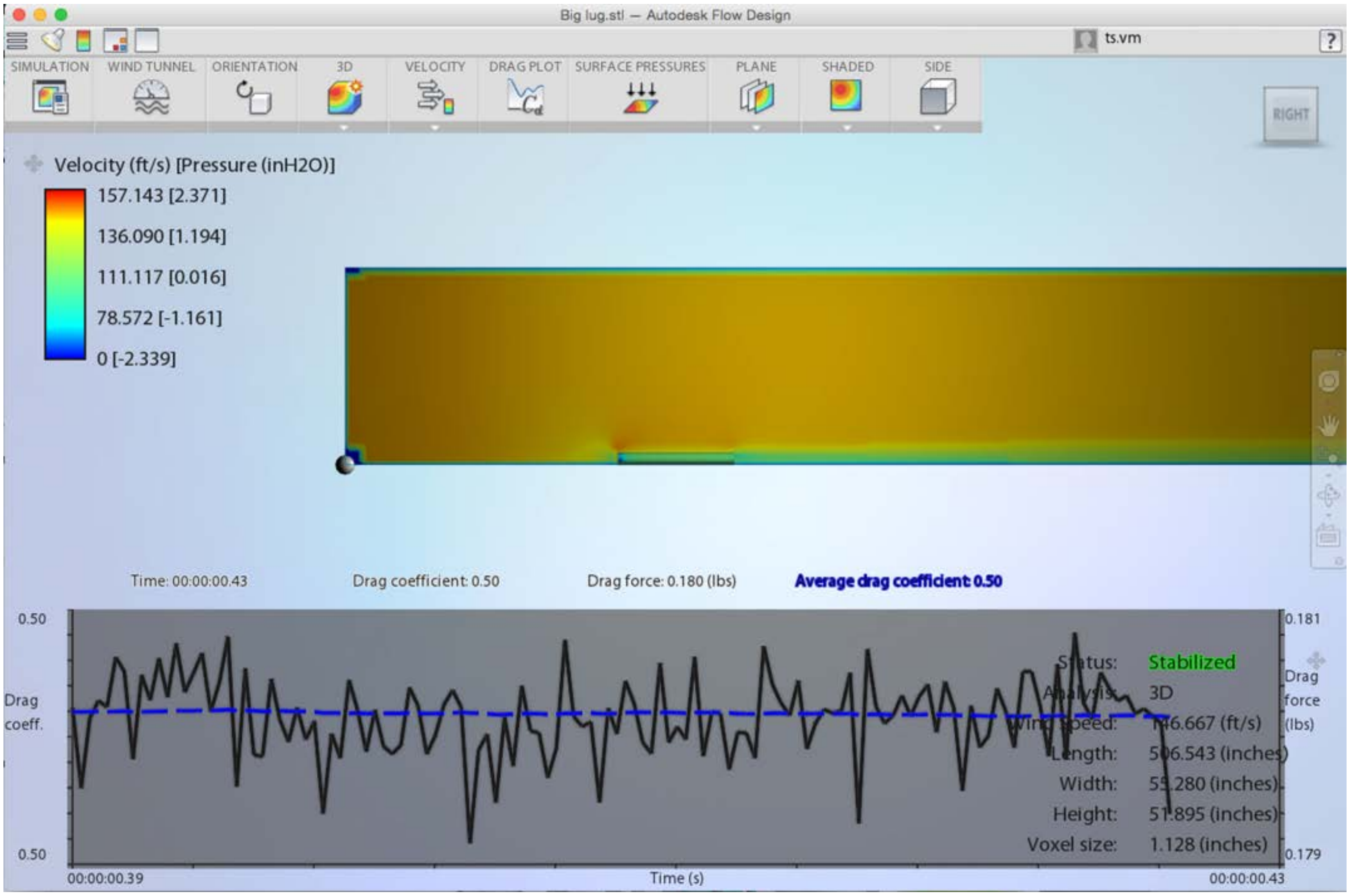
Sim #8 Drag of 1/8” X 0.1” long launch lug at 100 mph air flow



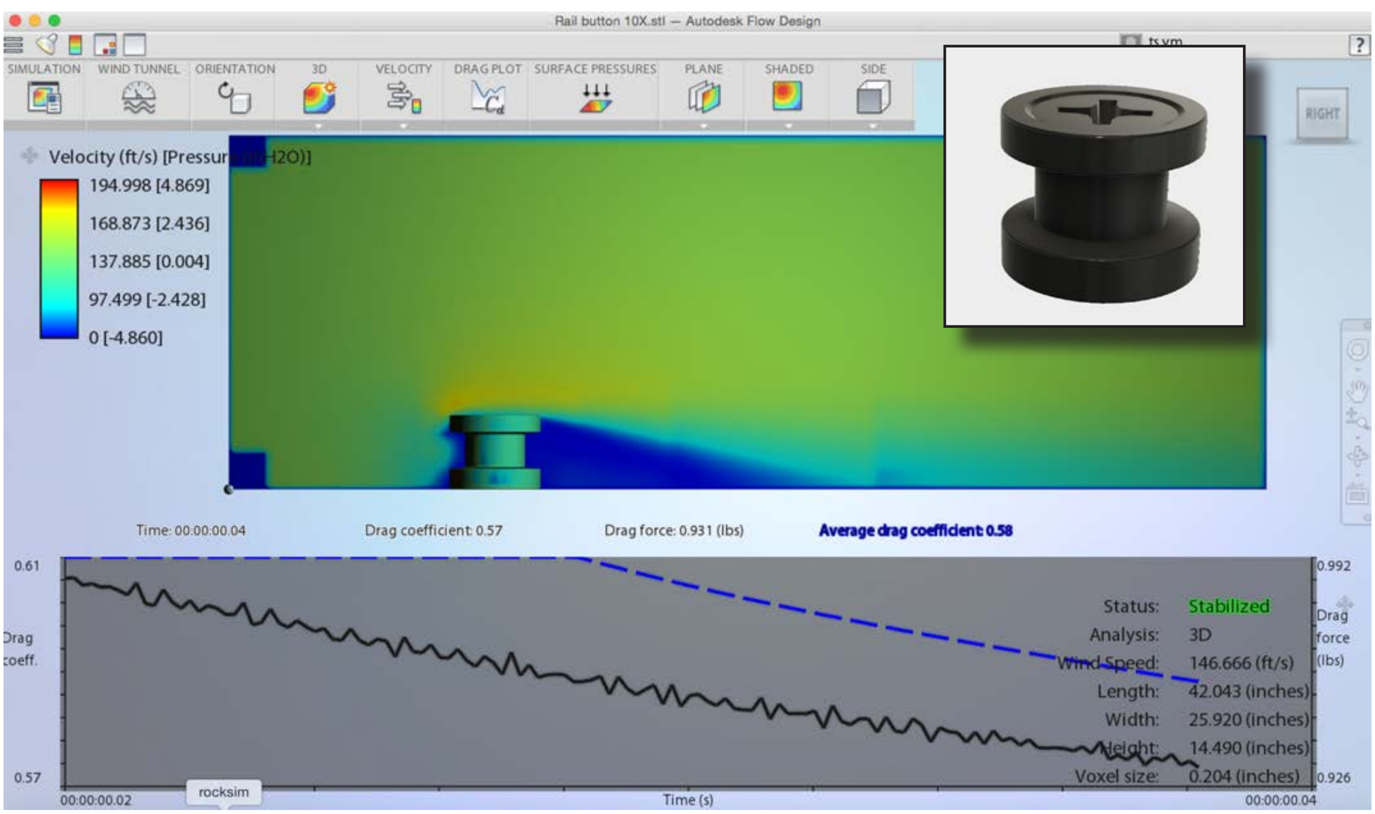
Sim #9 Drag of 1/8” Torus (a ring) launch lug at 100 mph air flow



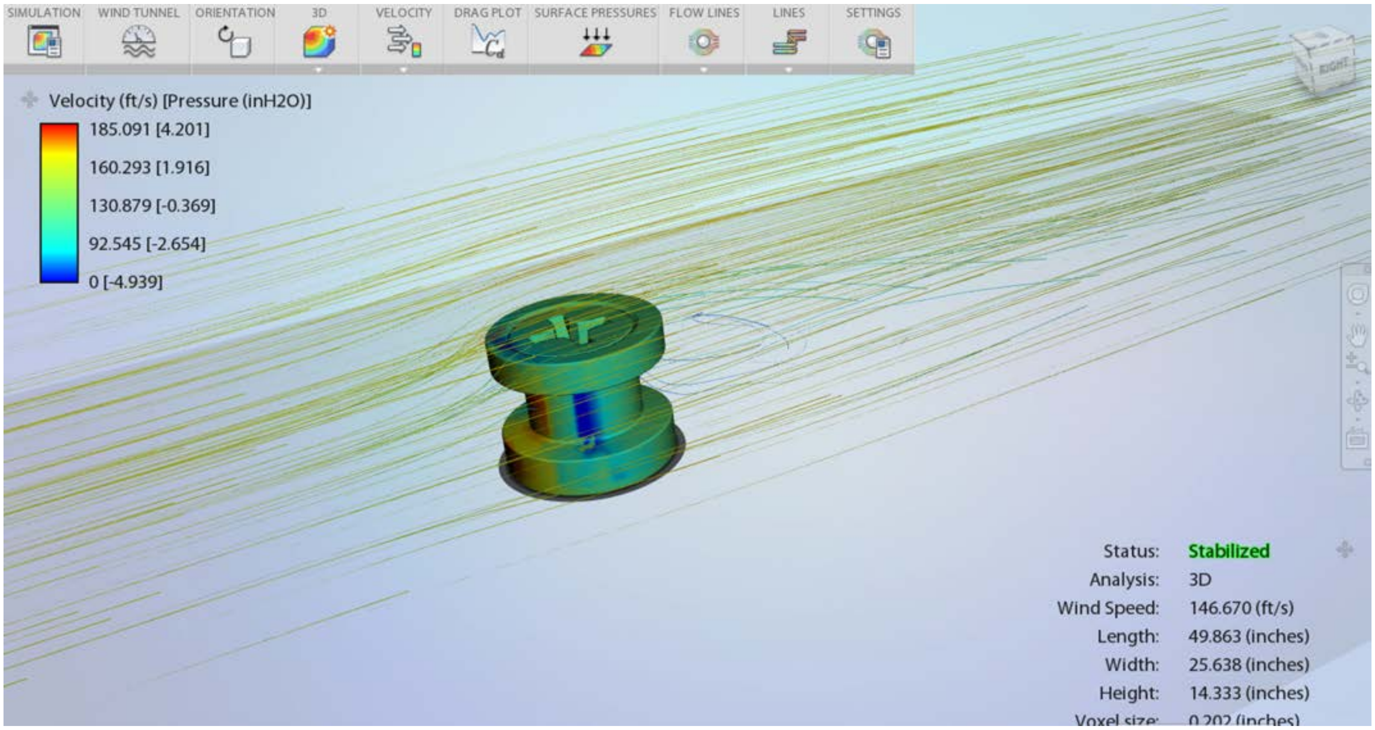
Sim #9 Velocity profile of 1/8” Torus (a ring) launch lug at 100 mph air flow



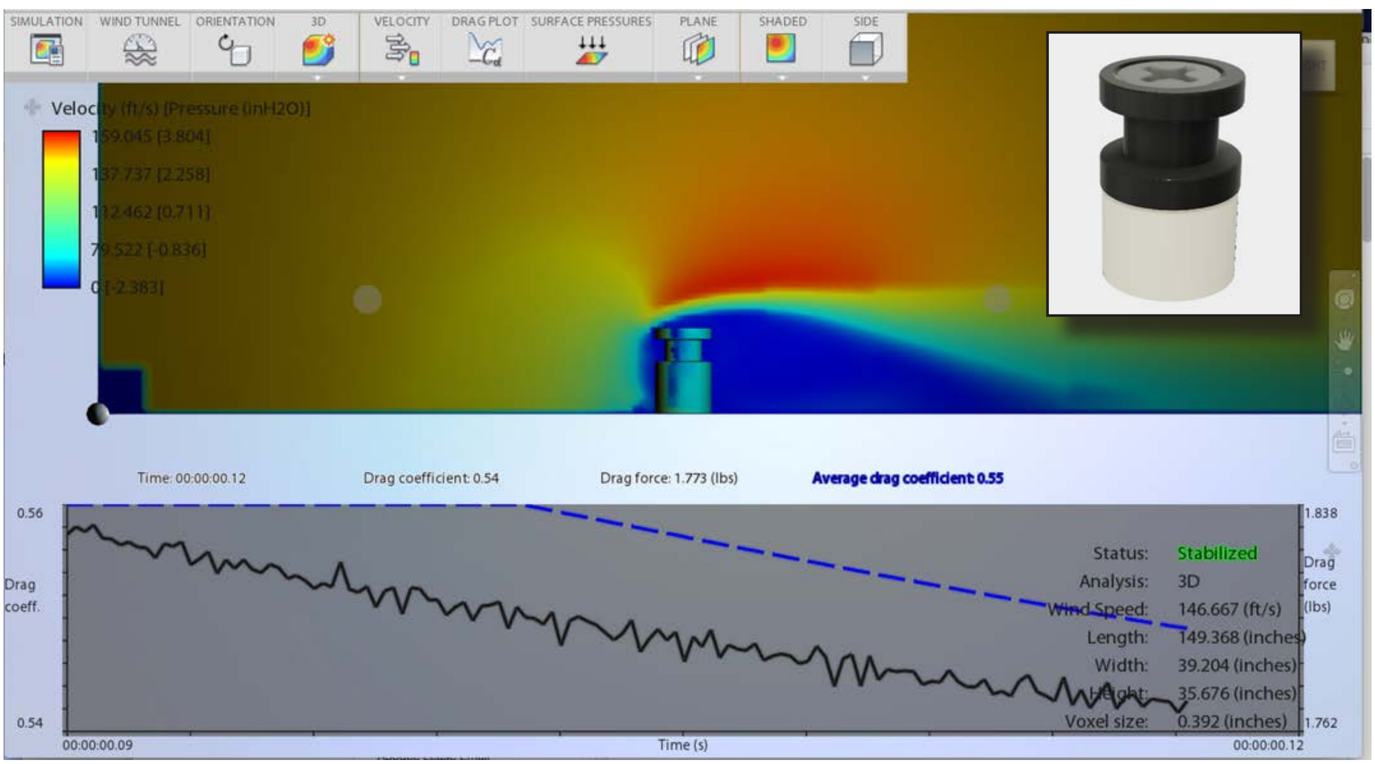
Sim #10 Drag of 1/4” dia X 3” long paper launch lug at 100 mph air flow



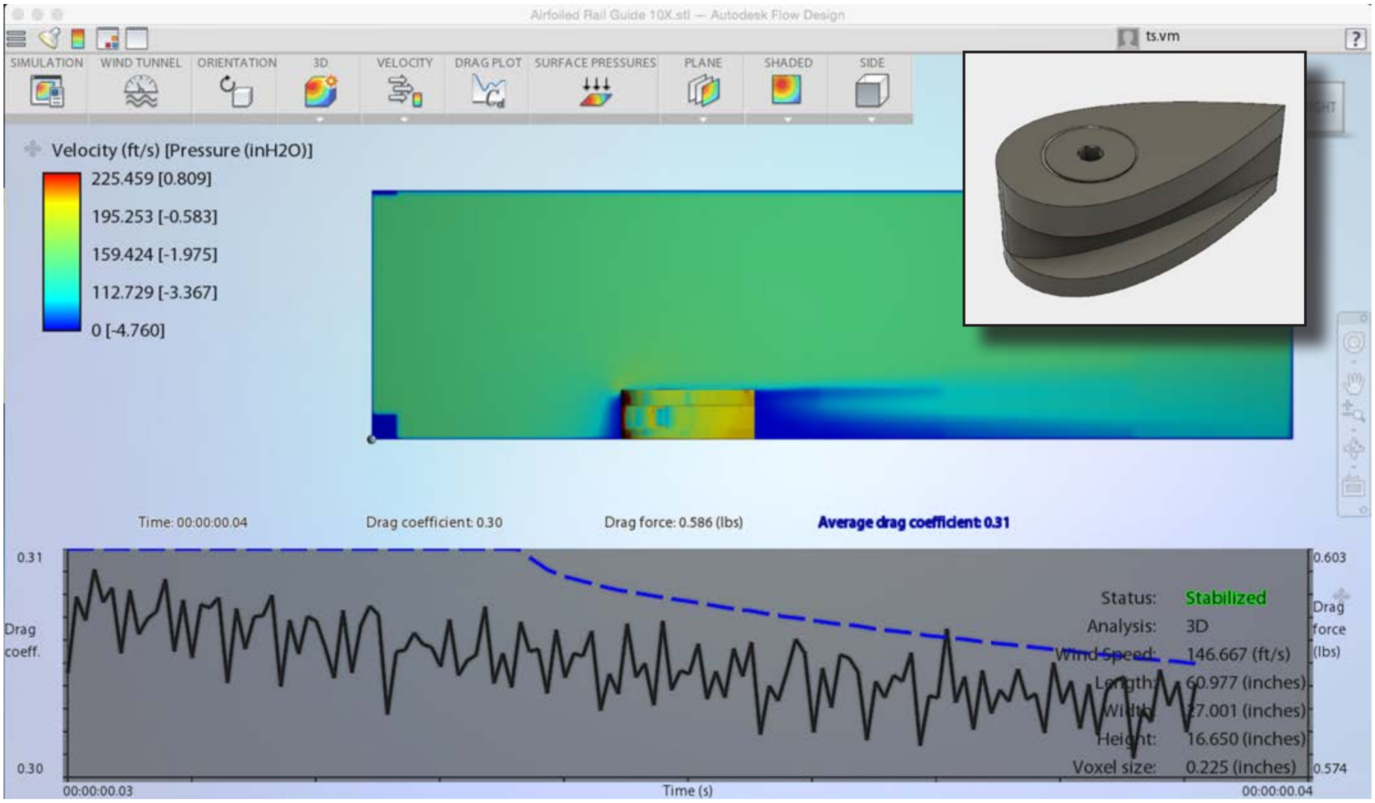
Sim #11 Drag of standard 1010 Rail button at 100 mph air flow



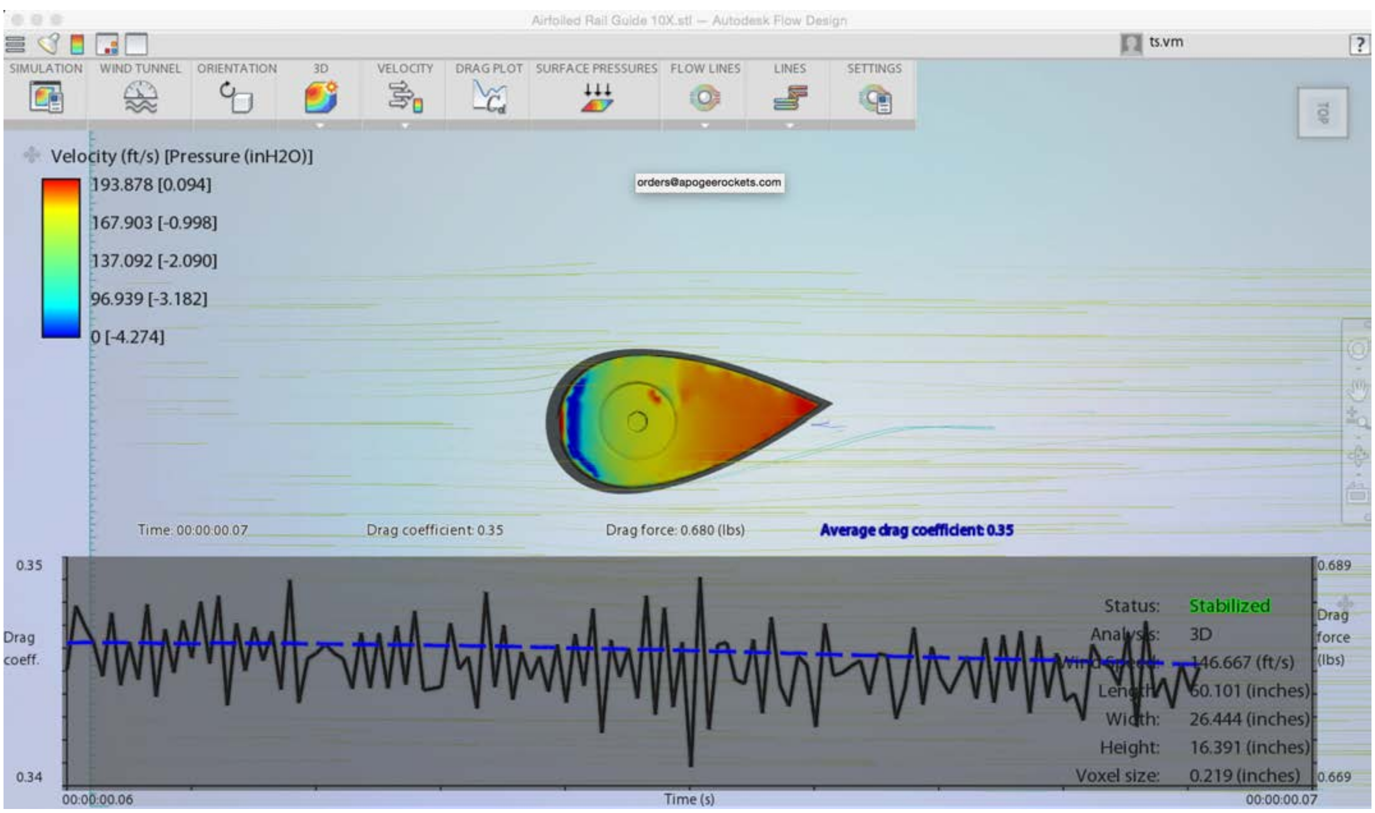
Sim #11 Flow lines around rail button show significant turbulence downstream of the rail button.



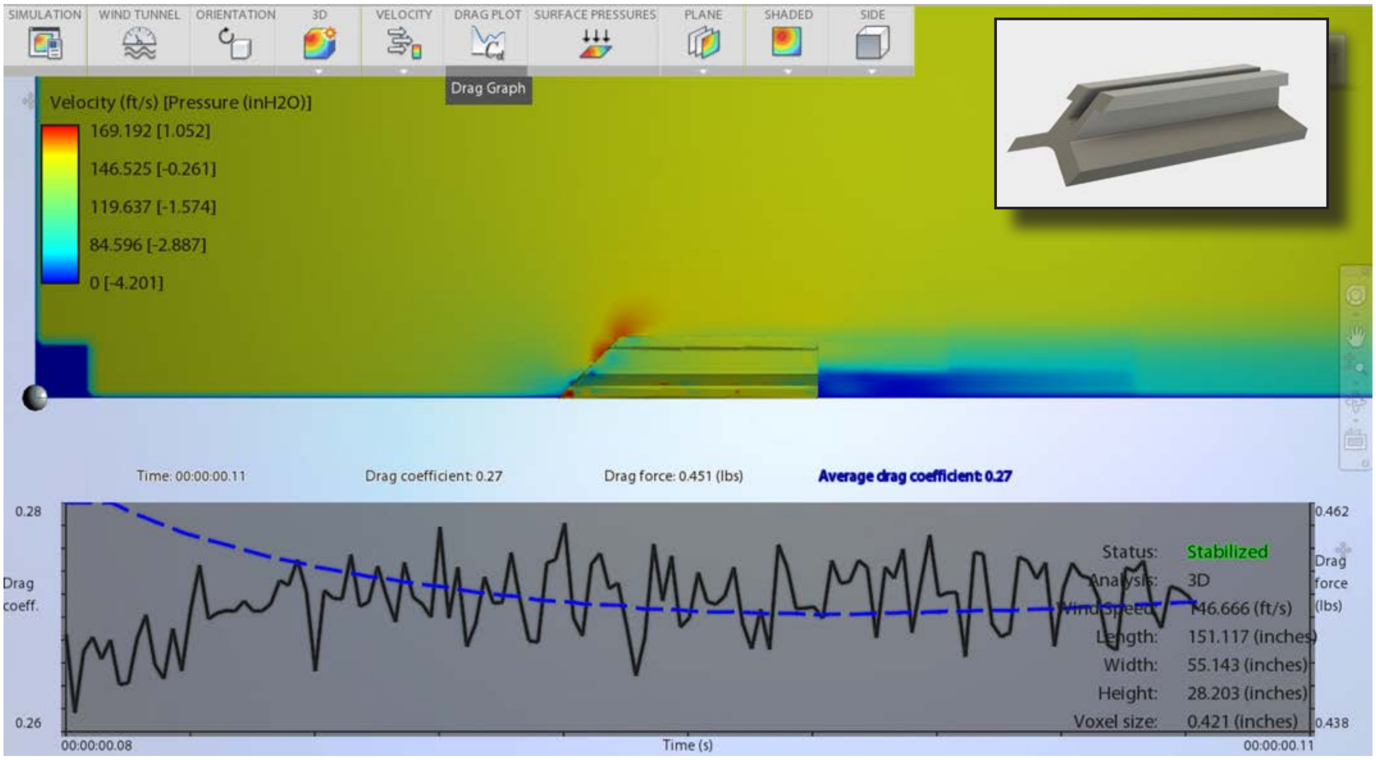
Sim #12 Drag of standard 1010 Rail button on a 1/4" high stand-off at 100 mph air flow



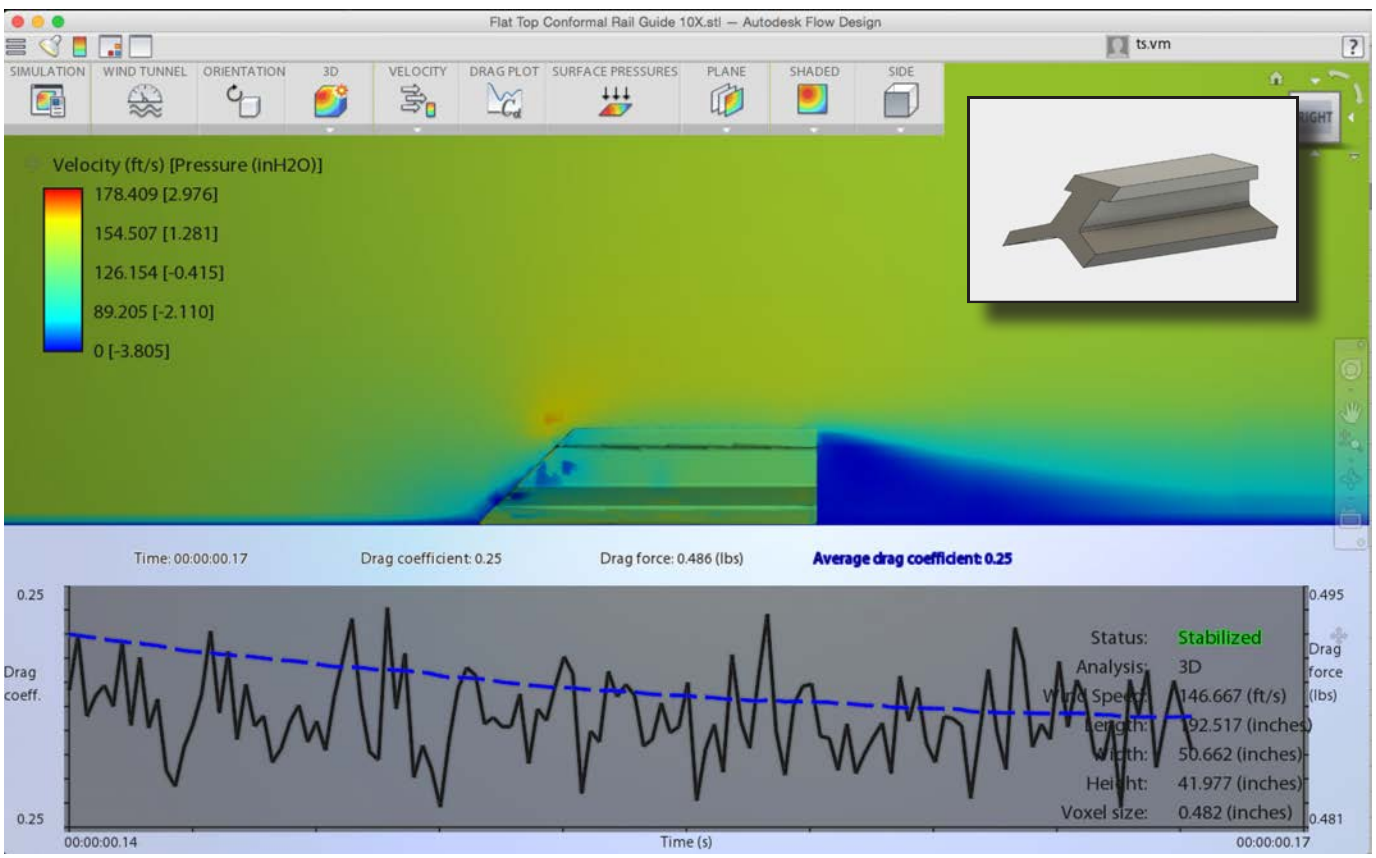
Sim #13 Drag of an airfoiled rail button (for a 1010 size launch rail) at 100 mph air flow



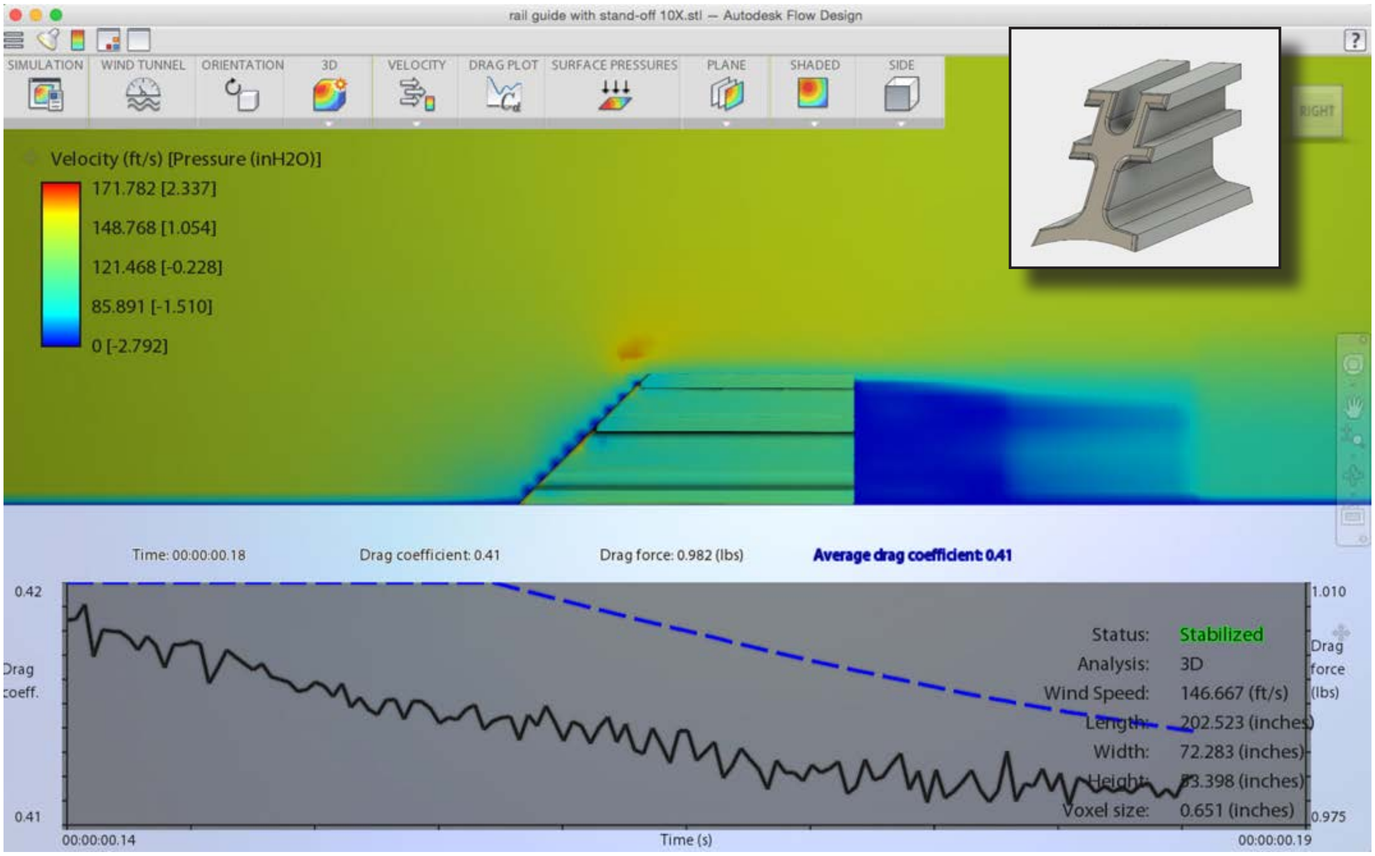
Sim #13 Flowlines around an airfoiled rail button (for a 1010 size launch rail) at 100 mph air flow at 5° AOA.



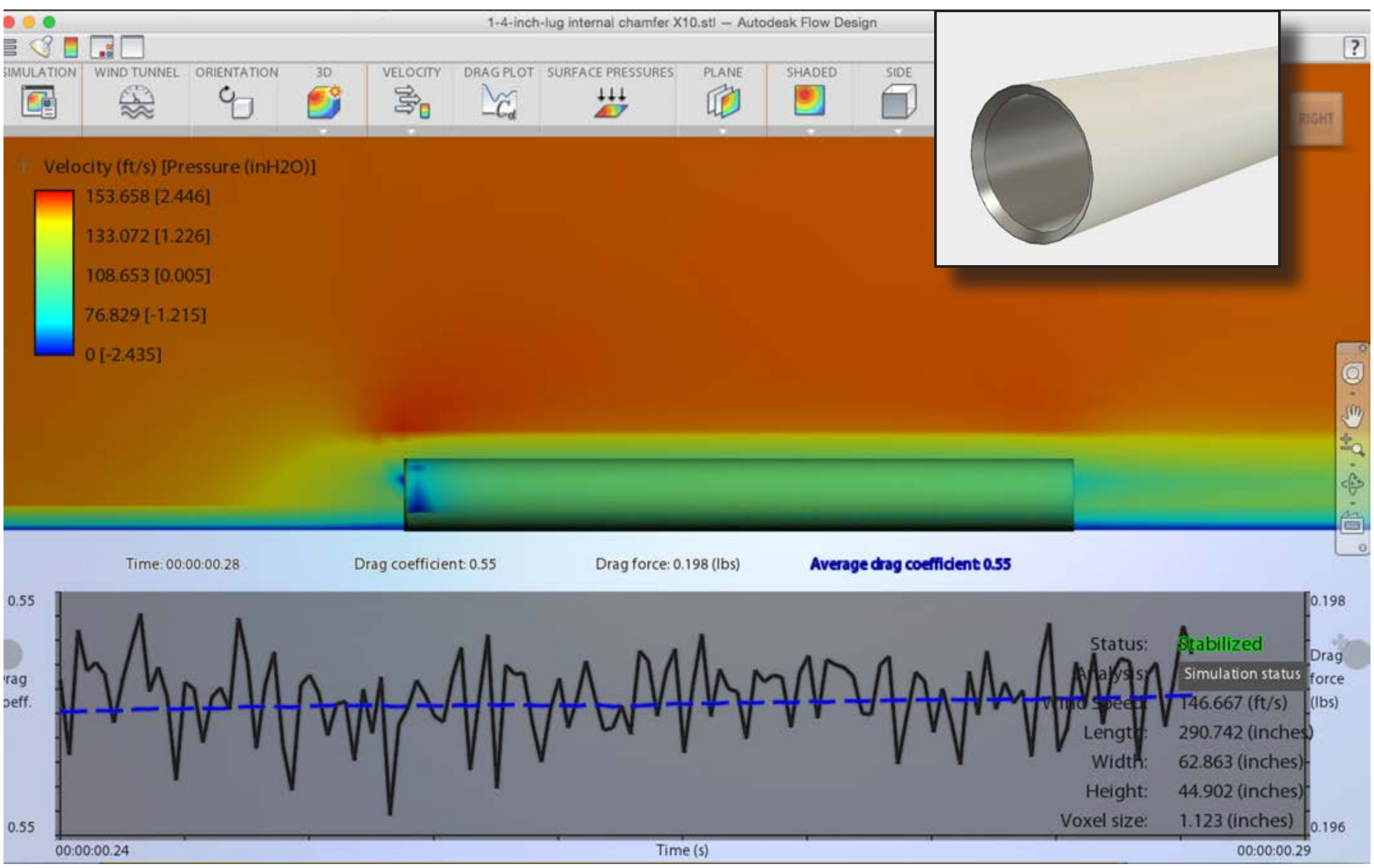
Sim #14 Drag on the Apogee Components Universal Rail Guide (split top) 100 mph air flow



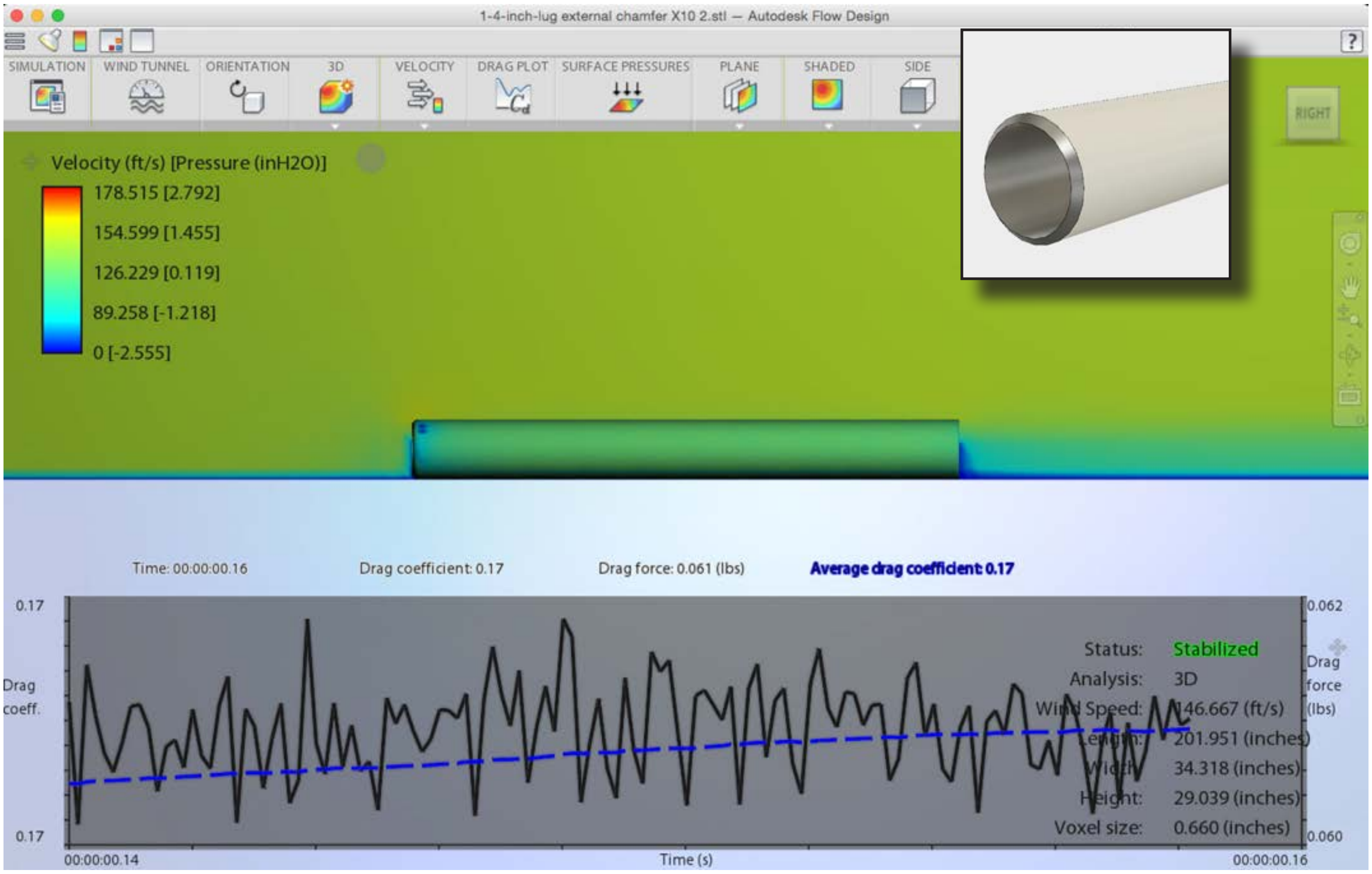
Sim #15 Drag on the “flat top” Rail Guide 100 mph air flow



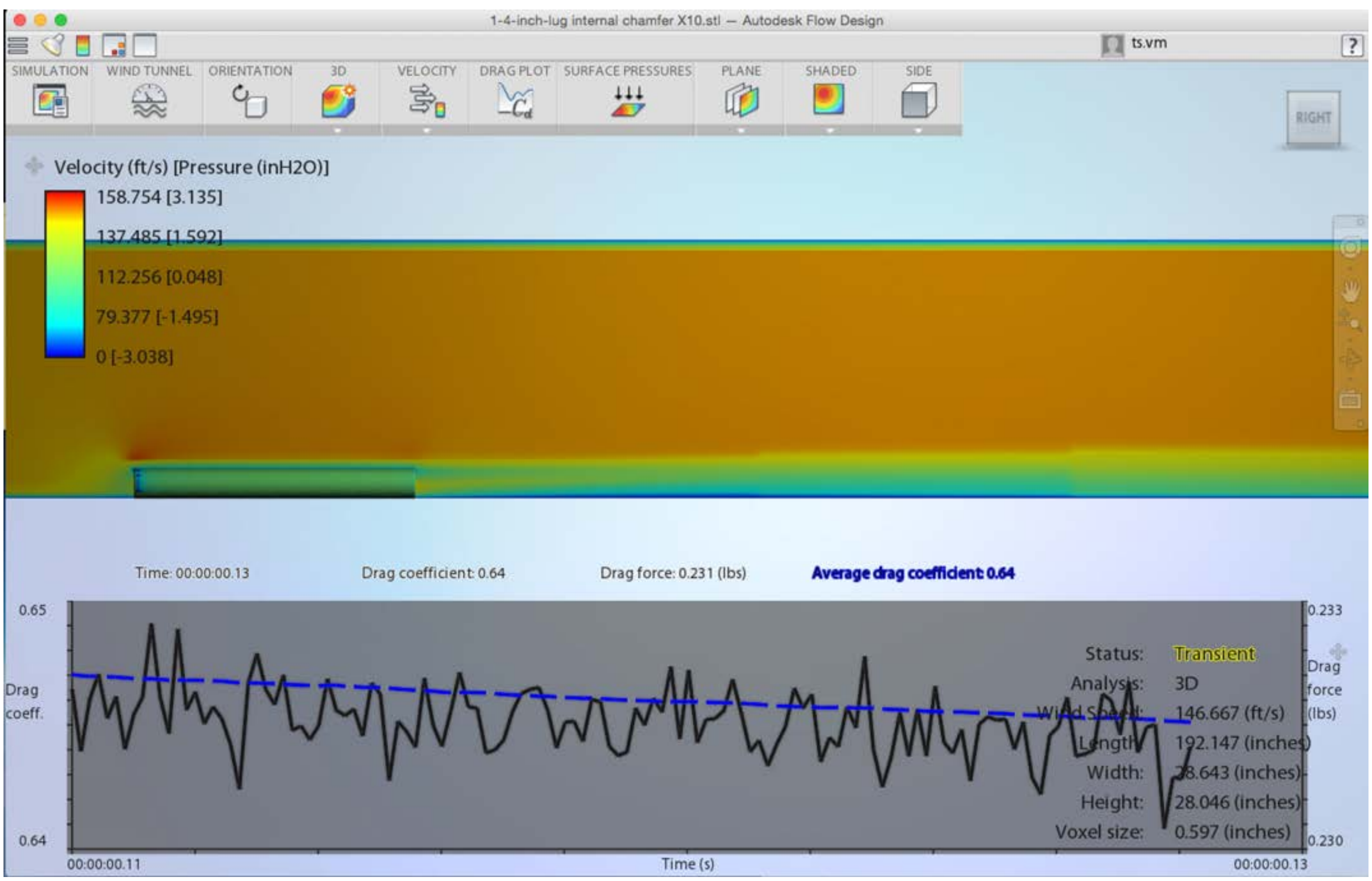
Sim #16 Drag on the Rail Guide with stand-off (BT-60 to BT-70 Size) 100 mph air flow



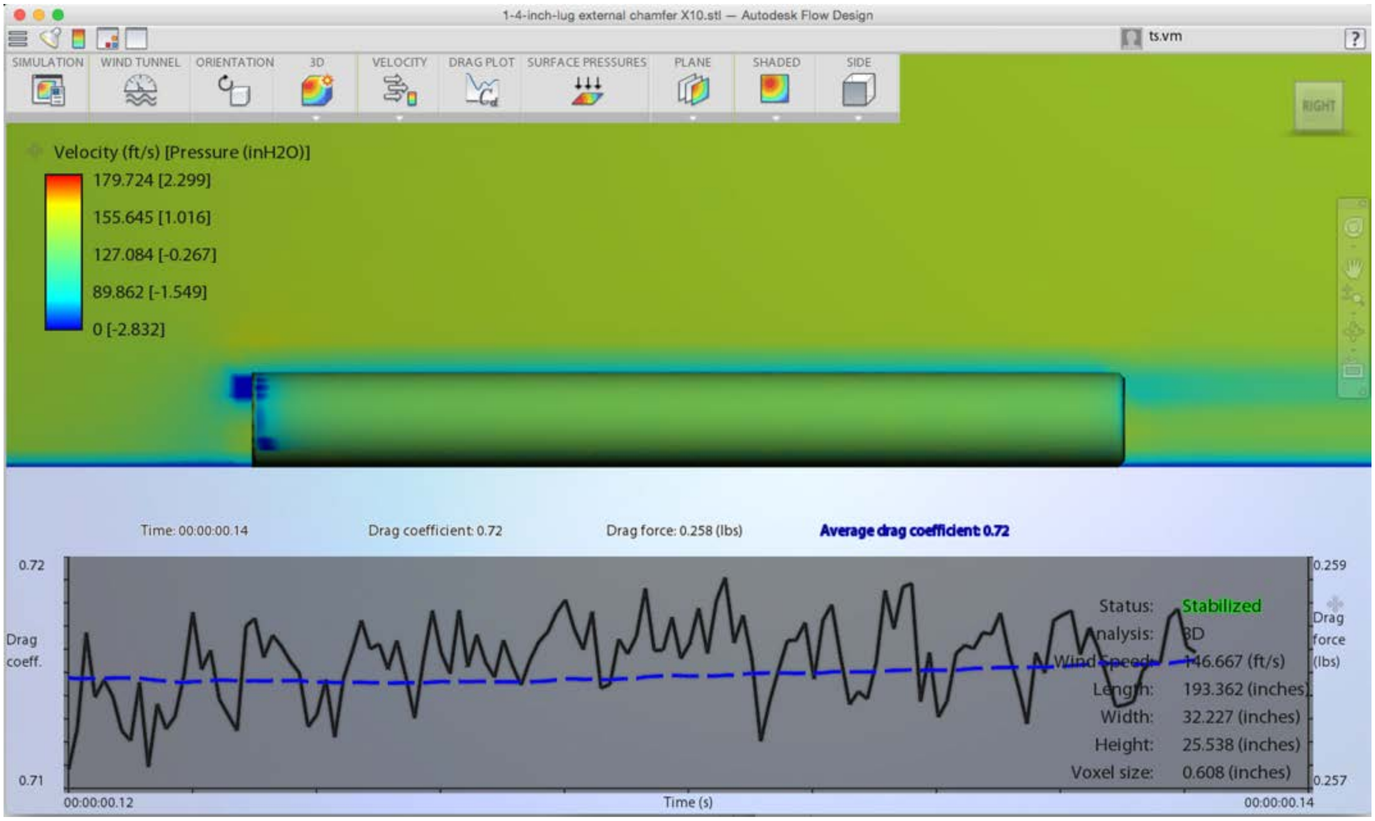
Sim #17 - 1/4” X 3” long lug with chamfer on inside of Leading Edge - 100 mph air flow



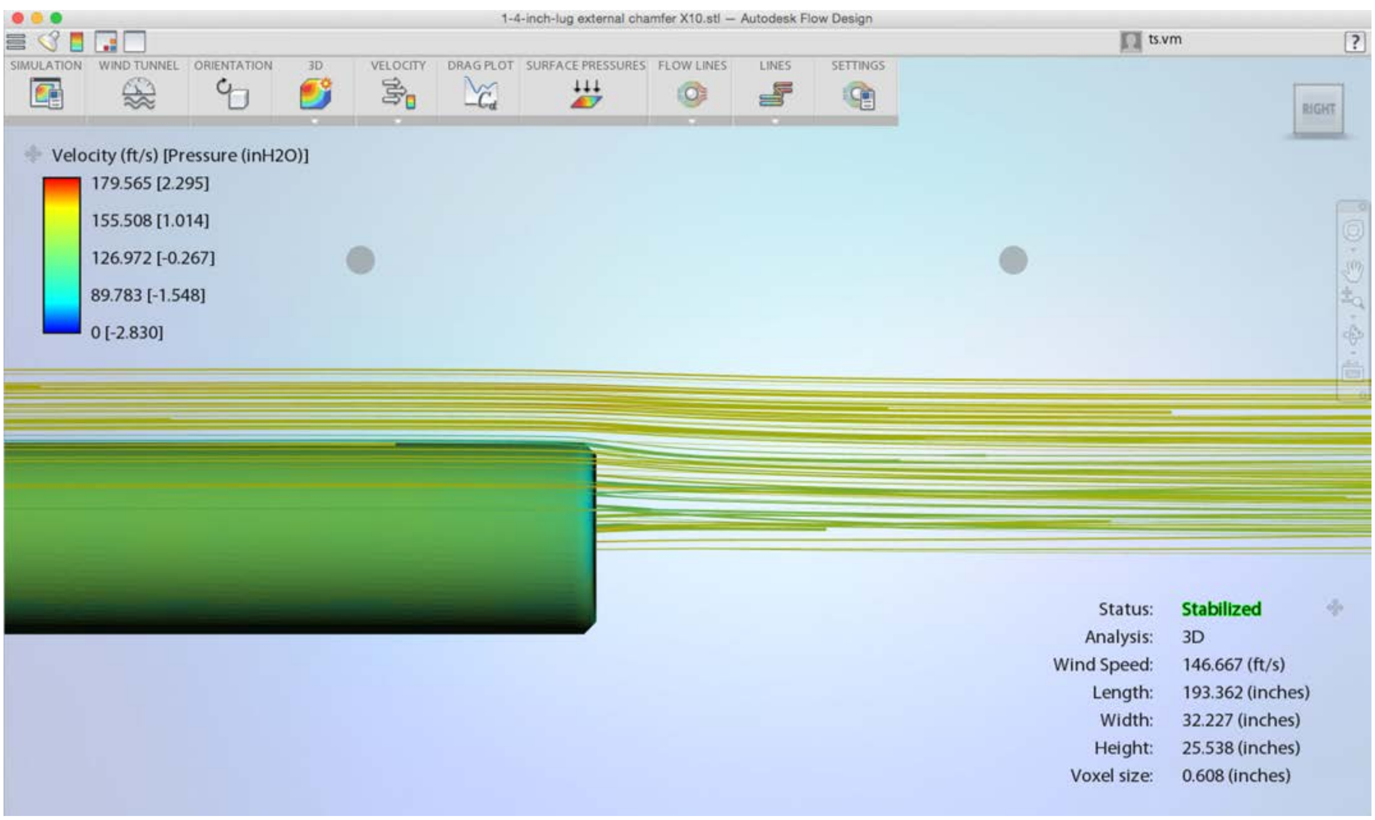
Sim #18 - 1/4” X 3” long lug with chamfer on outside of LE - 100 mph air flow



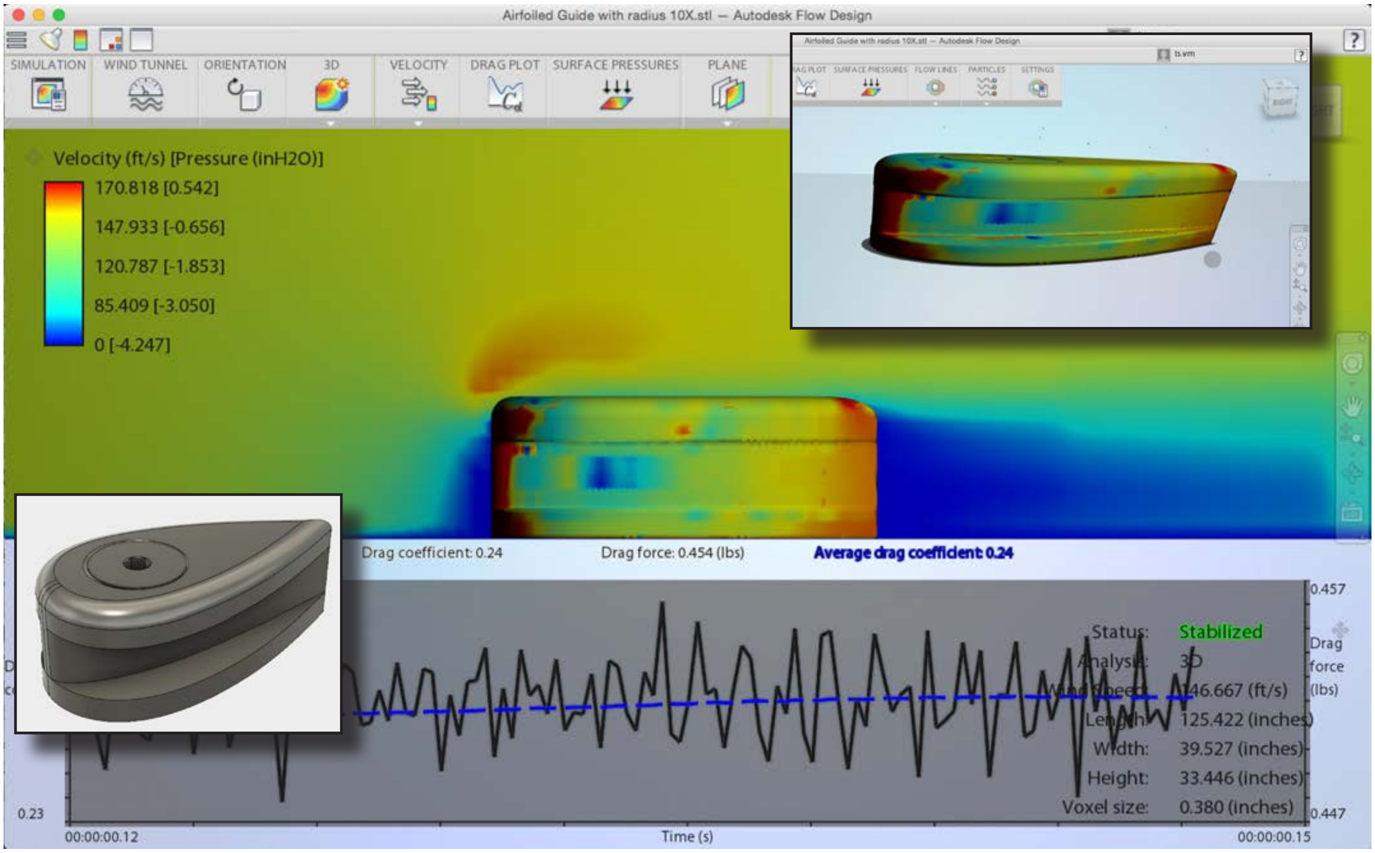
Sim #19 - 1/4” X 3” long lug with chamfer on Inside of Trailing Edge - 100 mph air flow



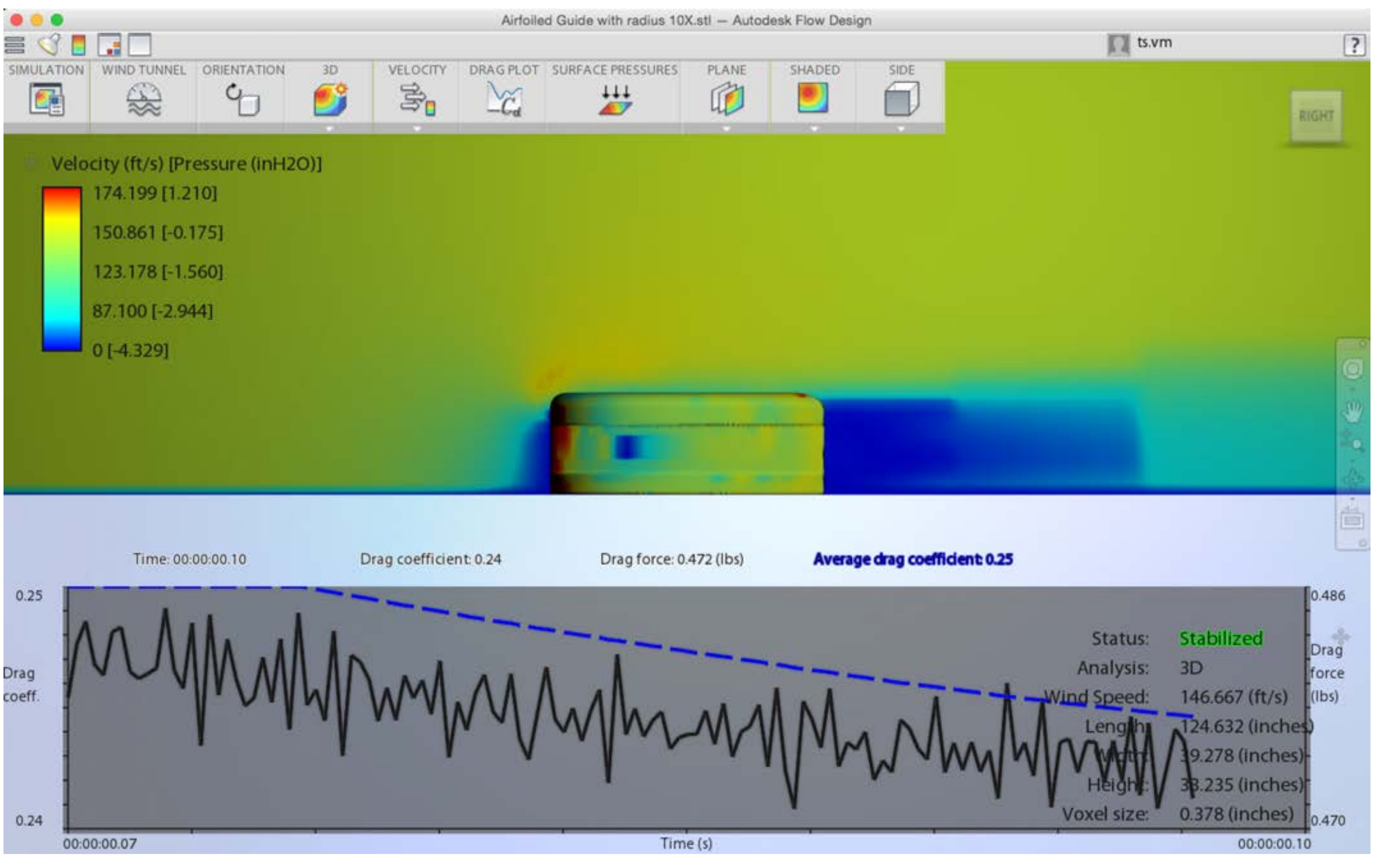
Sim #20 - 1/4" X 3" long lug with chamfer on Outside of Trailing Edge - 100 mph air flow



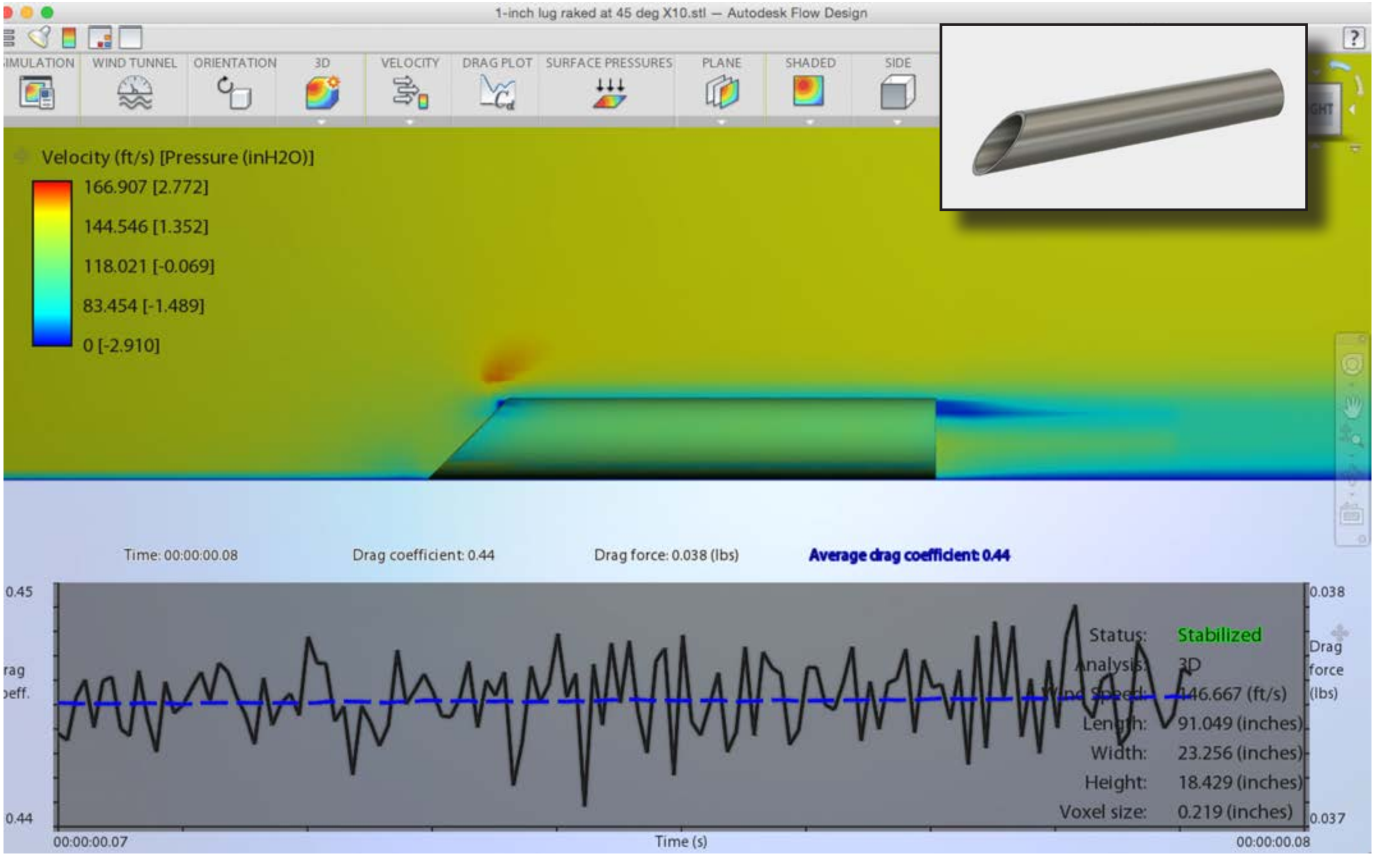
Sim #20 - Flow lines along 1/4" X 3" long lug with chamfer on Outside of Trailing Edge - 100 mph air flow



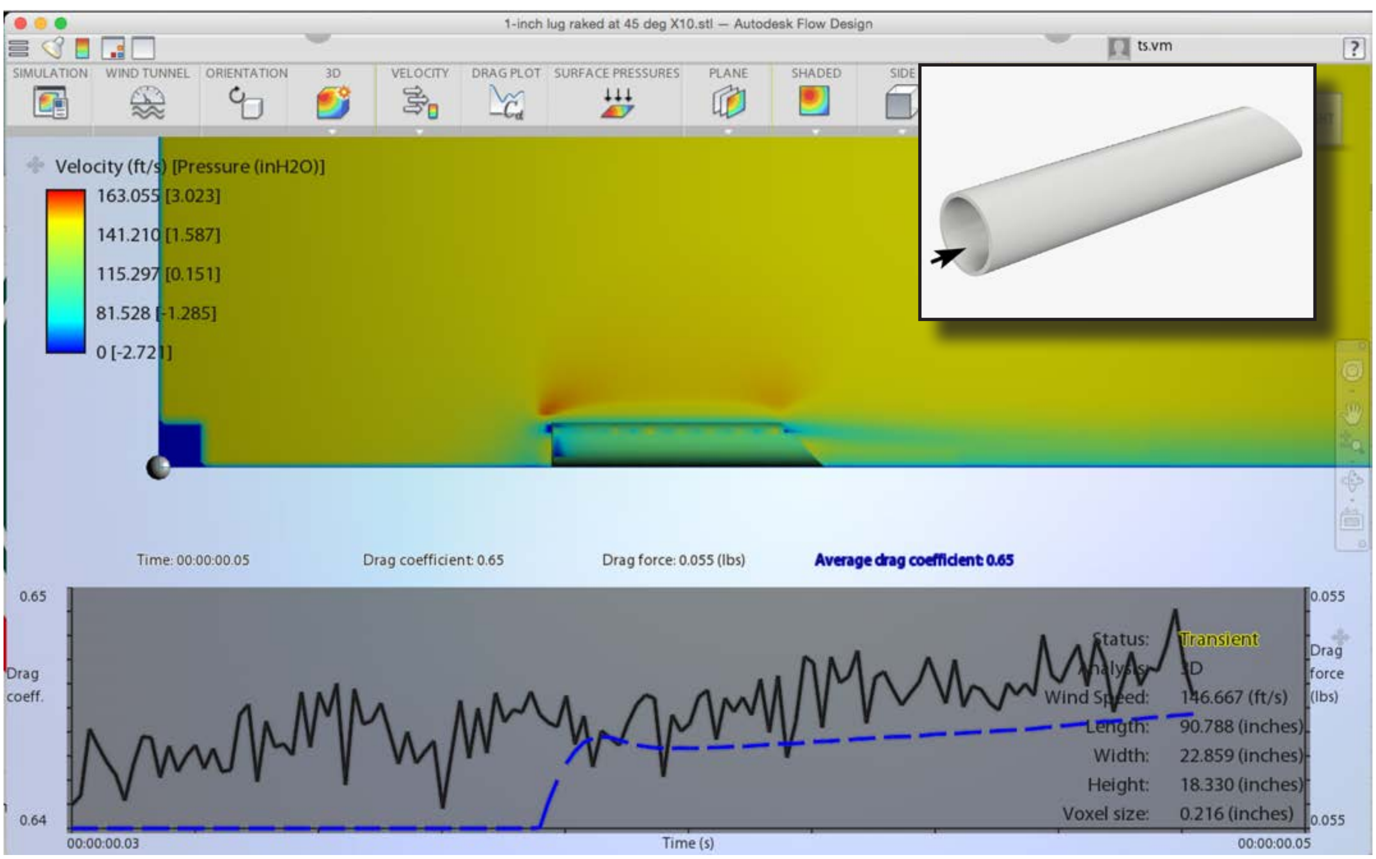
Sim #21 - Airfoiled Rail Button with radius on upper surface - 100 mph air flow - 0° A.O.A.



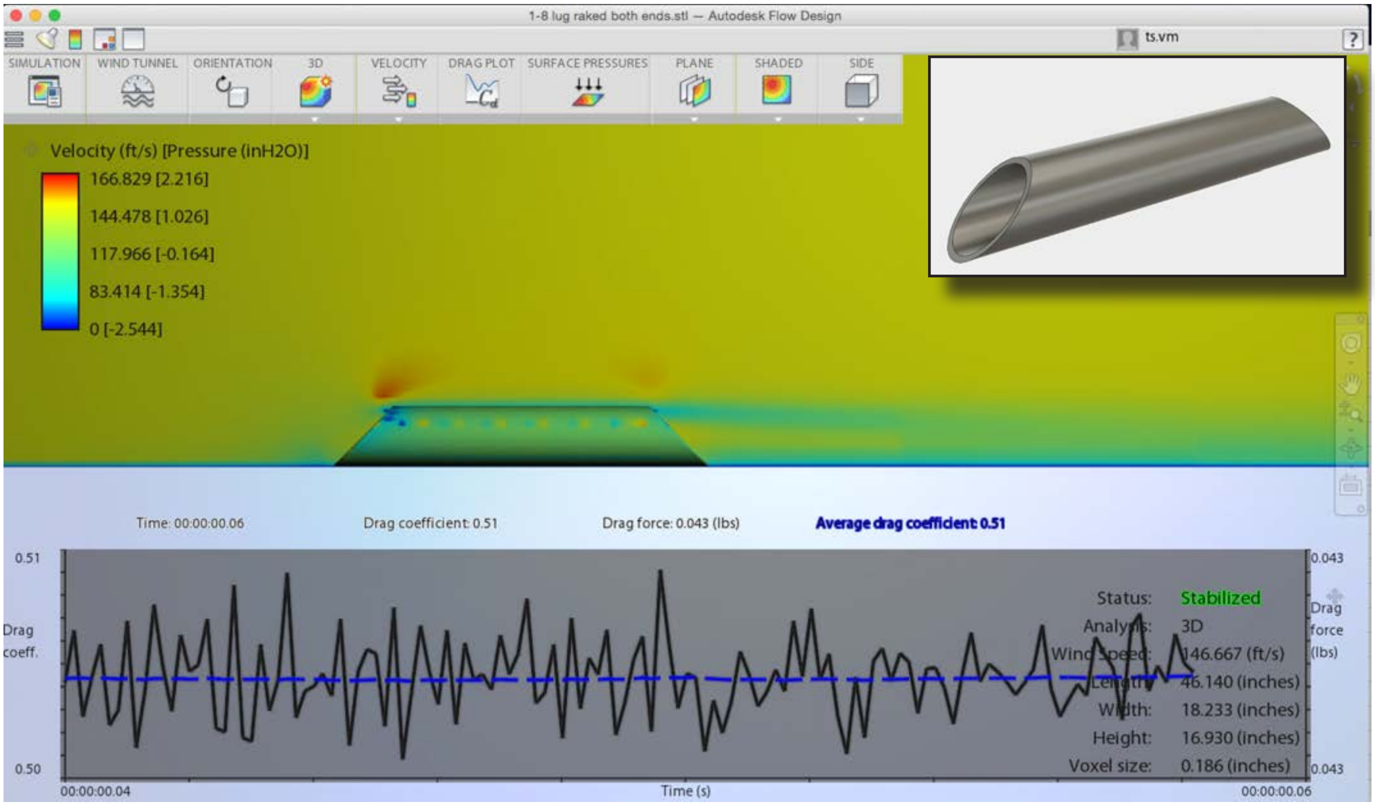
Sim #22 - Airfoiled Rail Button with radius on upper surface - 100 mph air flow - 5° A.O.A.



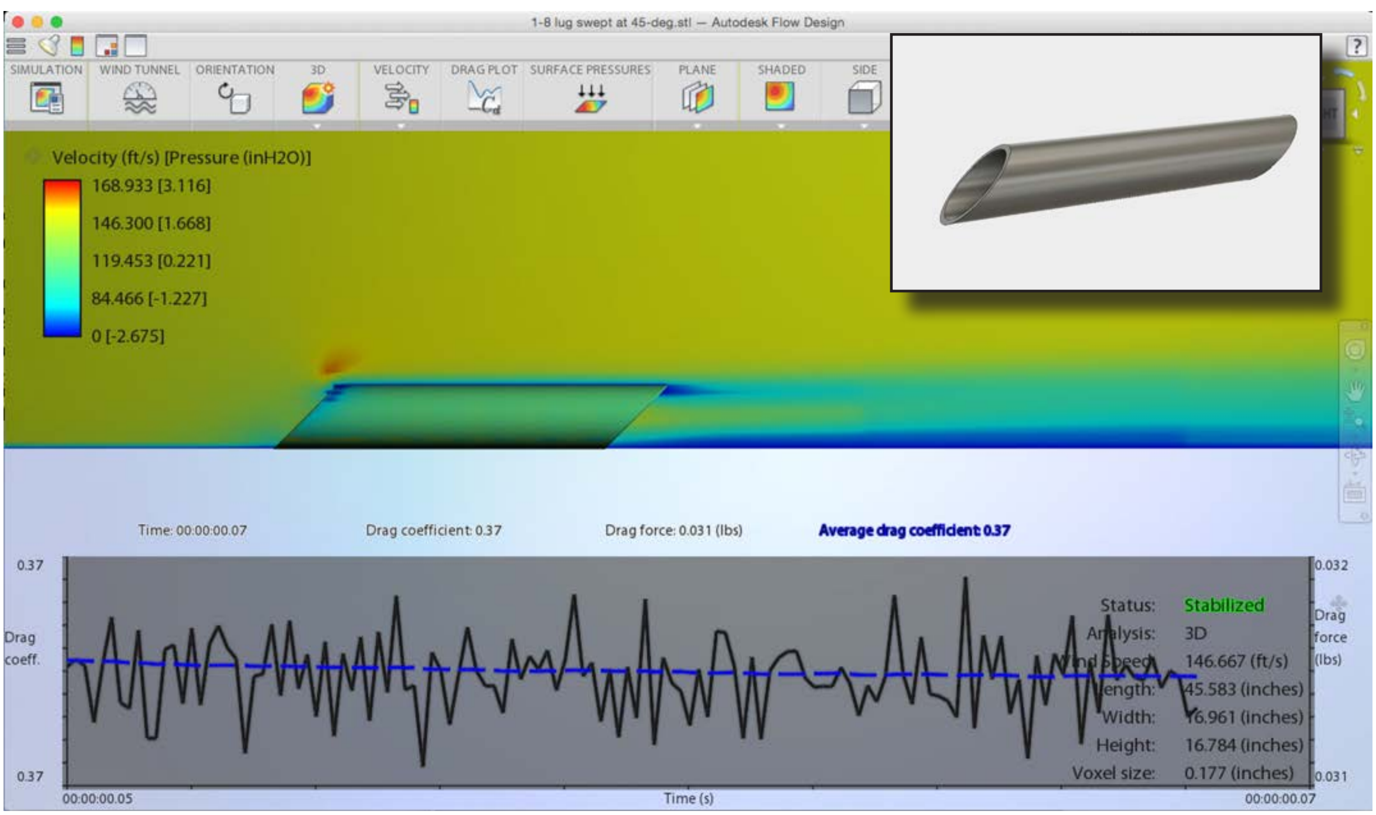
Sim #23 - 1/8” X 1” long launch lug with 45° raked Leading Edge - 100 mph air flow



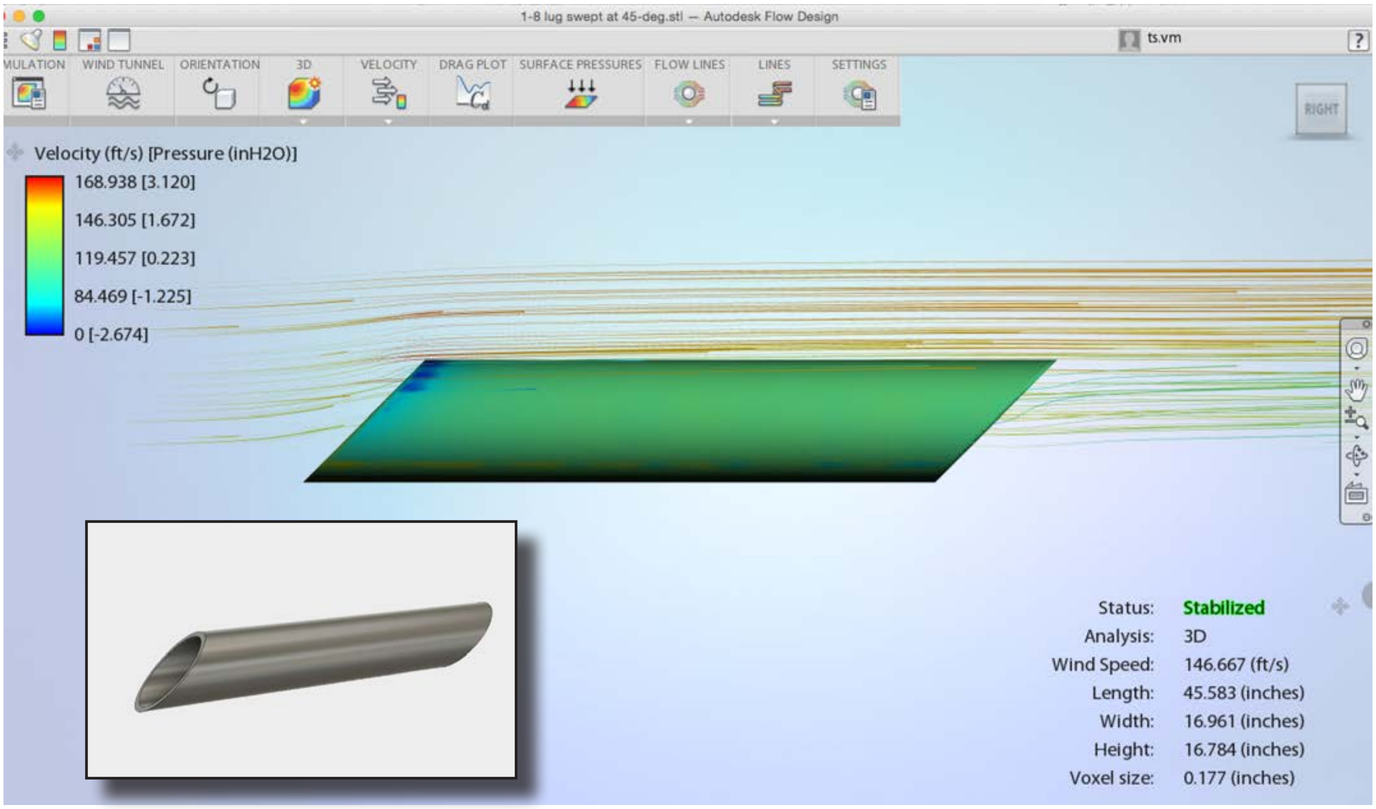
Sim #24 - 1/8” X 1” long launch lug with 45° raked Trailing Edge - 100 mph air flow



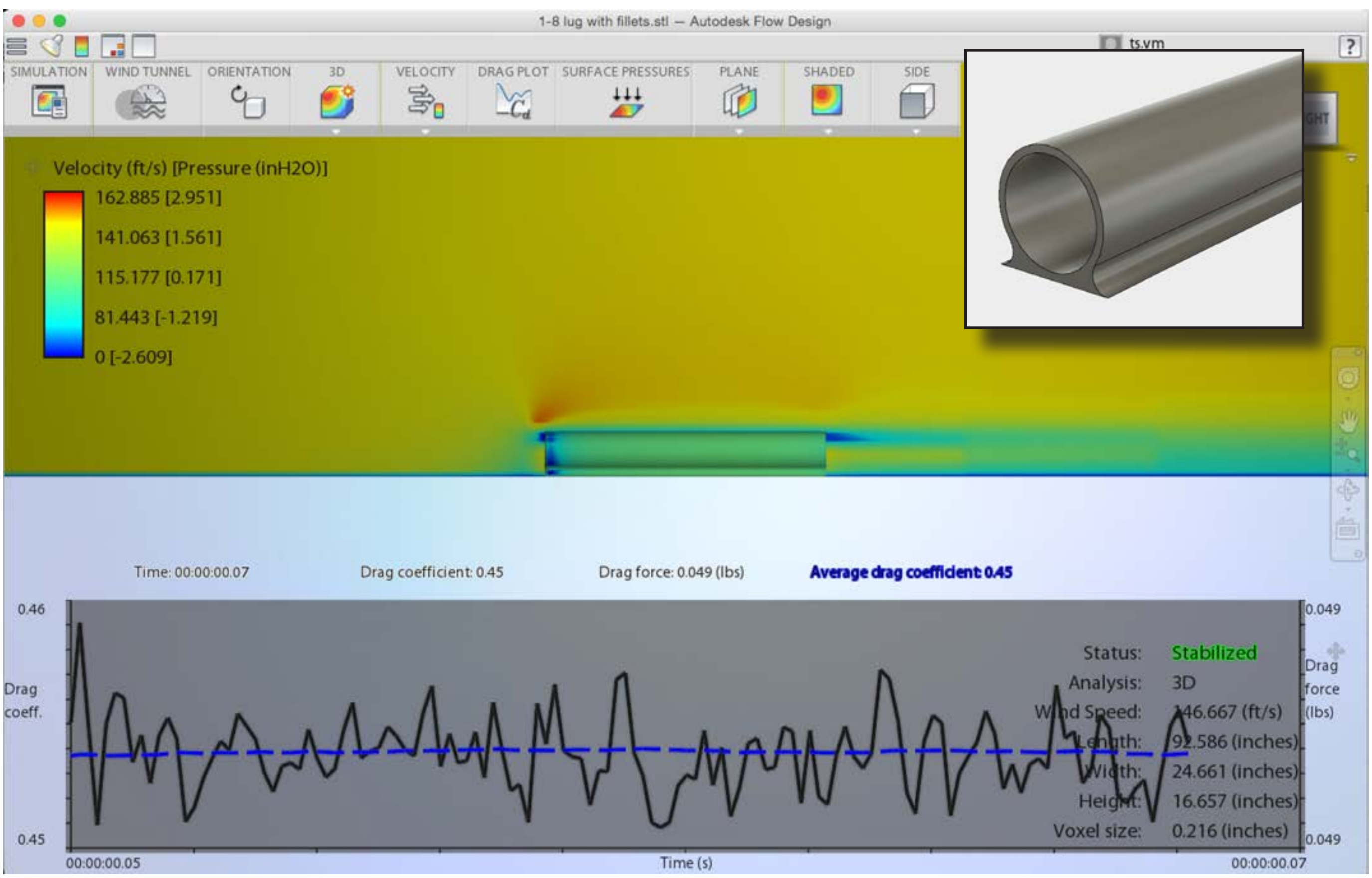
Sim #25 - 1/8” X 1” long launch lug with 45° raked Leading and Trailing Edges - 100 mph air flow



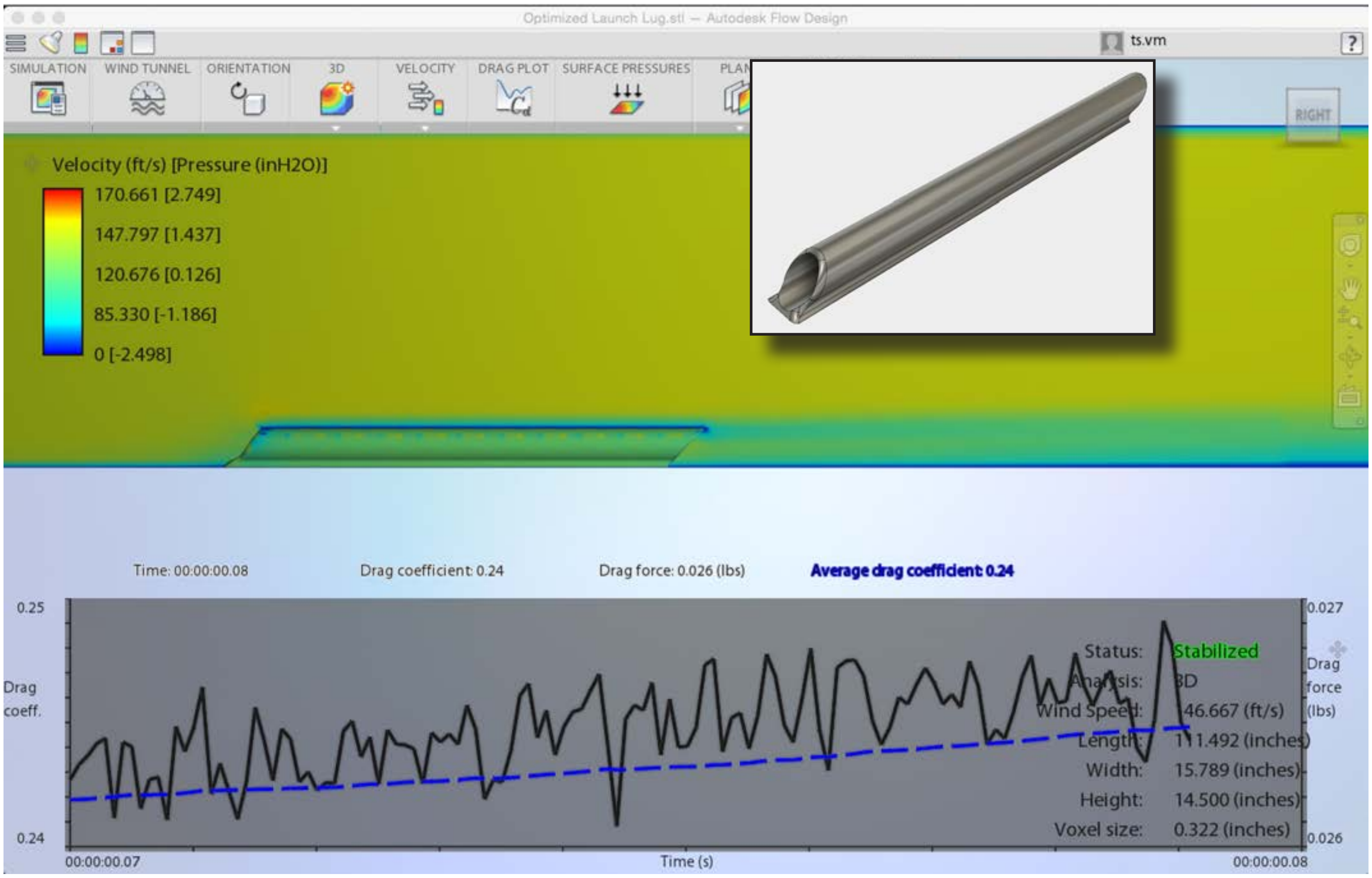
Sim #26 - 1/8” X 1” long launch lug with 45° swept Leading and Trailing Edges - 100 mph air flow



Sim #26 - 1/8" X 1" long launch lug with 45° swept Leading and Trailing Edges - Flow lines

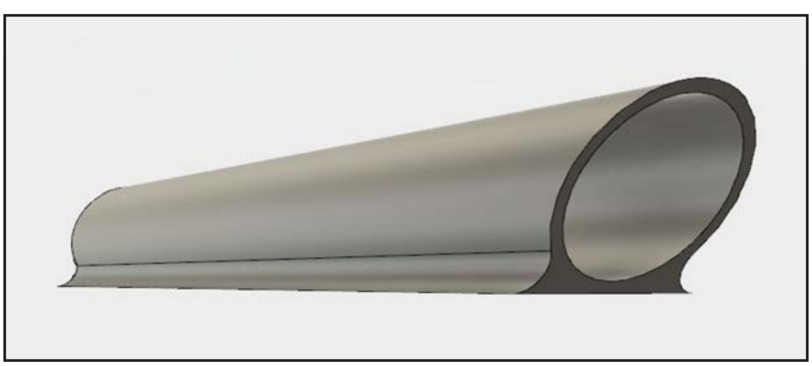


Sim #27 - 1/8" X 1" long launch lug with glue fillets - 100mph air flow



Sim #28 - 1/8” X 2” long launch lug with glue fillets, radiused LE, and Swept LE and TE - 100mph air flow


Sim #28 - 1/8” X 2” long launch lug with glue fillets, radiused LE, and Swept LE and TE - air flow stream-lines.


Sim #28 - Rear view of the 1/8” X 2” long launch lug with glue fillets, radiused LE, and Swept LE and TE.

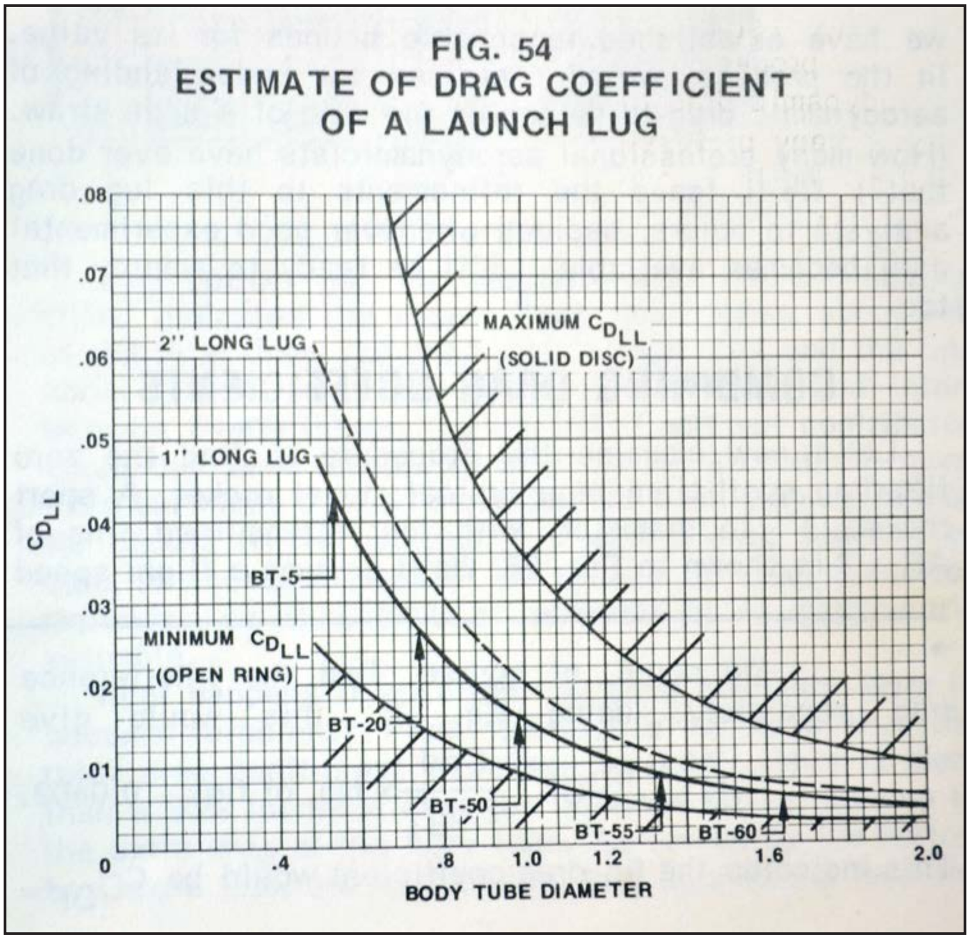
Summary Table

Sim #	Description	Cd	Drag (lbs)
1	Avion 1X No Lug	.38	0.101
2	Avion 1X With Lug	.38	0.101
3	Avion 10X No Lug	.35	9.382
4	Avion 10X With Lug	.41	10.907
5	1/8” X 1” Launch Lug	.60	0.051
6	1/8" X 2" long Launch Lug	.50	0.043
7	1/8" X 1/2" long Launch Lug	.75	0.064
8	1/8" X 0.1” long Launch Lug	.76	0.065
9	1/8" Torus ring	.93	0.154
10	1/4” X 3” Launch Lug Square Edge	.50	0.180
11	Rail Button	.57	0.931
12	Rail Button with 1/4” Stand-off	.54	1.773
13	Airfoiled Rail Button	.30	0.586
14	Universal Rail Guide	.27	0.451
15	Universal Rail Guide with Flat Top	.25	0.486
16	Rail Guide with Stand-off (BT-60 to BT-70)	.41	0.974
17	1/4" X 3" Launch Lug Internal LE Chamfer	.55	0.197
18	1/4" X 3" Launch Lug LE External Chamfer	.17	0.061
19	1/4" X 3" Launch Lug Internal TE Chamfer	.64	0.231
20	1/4" X 3" Launch Lug TE External Chamfer	.72	0.258
21	Airfoiled Rail Button with Rounded Edge	.24	0.454
22	Airfoiled Rail Button with Rounded Edge at 5° AOA	.25	0.472
23	1/8” X 1 Launch Lug with 45° Raked L.E.	.44	0.038
24	1/8” X 1 Launch Lug with 45° Raked T.E.	.65	0.055
25	1/8” X 1 Launch Lug with 45° Raked L.E. & T.E.	.51	0.043
26	1/8” X 1 Launch Lug with 45° Swept L.E. & T.E.	.37	0.031
27	1/8” X 1” Launch Lug with fillets	.46	0.049
28	1/8" X 2" Optimized Lug with fillets	.24	0.026

The Results Obtained

Once I figured out how to use the Flow Design software and generated results for the baseline condition of the 1/8” X 1” long lunch lug, I started the real work of changing some of the variables.

I first varied the length of the launch lug. To start, I made it twice as long. This was my first head-scratching moment when I said to myself: “well look at that.” I expected the drag to go up, which is what Dr. Gerald M. Gregorek indicates in *TR-11 Aerodynamic Drag of Model Rockets*.



However, according to the CFD simulation, both the drag coefficient and force actually decreased. The C_d decreased by 16.7% compared to the 1” long launch lug.

Based on this unexpected result, I decided to see what the software would compute for the drag if I made the launch lug shorter. Simulations showed it did predict that a shorter lug did indeed have higher drag. The limiting case situation, of a torus (a ring), showed the worst drag of all.

I also wanted to get the base configuration of a standard 1/4” X 3” long paper launch lug (https://www.apogeerockets.com/Building_Supplies/Launch_Lugs_Rail_Buttons/Launch_Lugs/1_4_Launch_Lug). The software computed a C_d of 0.50, and a drag force of 0.180 lbs.

This C_d value was something that I was expecting to see. If the proportions are the similar, the C_d should stay approximately the same. In this case, the 1/8” diameter X 2” long lug are in the same ballpark ratio as the 1/4” diameter X 3” long lug. It was a good confirmation that the software seemed to be working - at least as far as consistency goes for objects of similar proportions.

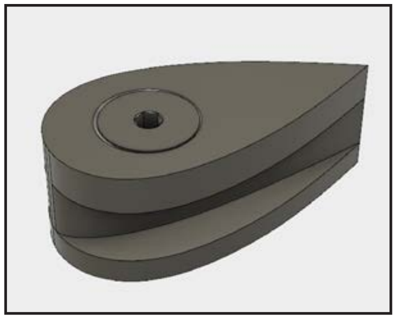
My next computer simulation was to input a standard rail button for a 1010 launch rail (https://www.apogeerockets.com/Building_Supplies/Rail_Buttons/1in_1010_Rail_Button_Standard). This time the result shocked me. The C_d of the rail button computed to be 0.57. But that is deceiving, because the drag was estimated at 0.931 lbs. This is a 78.8% increase in the drag force compared to a 1/4” dia X 3” long paper launch lug.

The results say that if you have a choice between using a 1/4” lug, or a rail button, the lug will have significantly lower drag.

For the next experiment, I wanted to see what happened when you put the rail button on a stand-off. A stand-off is used when you have a protrusion on the rocket that interferes with the launch rail. In most cases, it is a bulbous nose cone that doesn’t allow the rail to lay along side of the rocket.

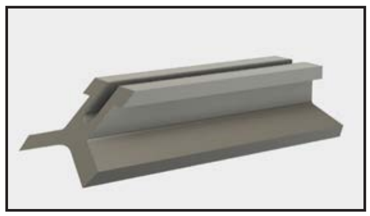
When a 1/4” tall stand-off post (such as: https://www.apogeerockets.com/Building_Supplies/Launch_Lugs_Rail_Buttons/Rail_Buttons/1_8_Rail_Button_Standoff) is put in combination with the rail button the drag increases dramatically. Comparing the actual drag against a standard button without a standoff, the drag increase 90.4%. This is a huge increase, which indicates that you should always try to mimize any protrusions sticking off the side of the tube. They will add a lot of drag.

Apogee Components also sells an airfoiled rail button (https://www.apogeerockets.com/Building_Supplies/Launch_Lugs_Rail_Buttons/Rail_Buttons/Standard_Airfoiled_Rail_Buttons). The questions I’ve always had about this product are: “Is this a gimmick just to get your money? How much drag reduction do you get by going to airfoiled rail buttons?”



The answer, according to the CFD software simulations, is that there actually is a drag reduction by going to the airfoiled rail buttons. Compared to the standard round rail button, the drag of the airfoiled rail button is 37.1% lower.

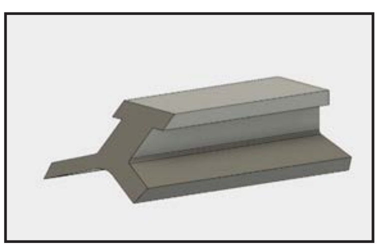
My next shape experiment was with rail guides. Rail Guides are essentially elongated rail buttons, but are rectangular rather than circular. They were developed by manufacturers because they don't require a post and screw hardware to attach them to your rocket. You can simply bond them to the outside of the rocket with some epoxy. You don't need to drill a hole in the side of your rocket's tube like you do with a rail button.



This was another "well look at that" moment. Since the rail guides are larger, I would have expected a higher amount of drag. But the drag of the Universal Rail Guide (https://www.apogeerockets.com/Building-Supplies/Launch-Lugs-Rail-Buttons/Rail-Buttons-Guides/Universal-Rail-Guides) actually was a lot lower - about half of a standard rail button's drag force. They are also lower in drag than the un-modified airfoiled rail buttons.

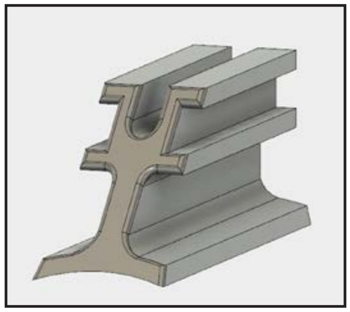
Next, I wanted to see how much drag difference there would be between a standard 'split-top' rail guide, and the 'flat top' version. The split top is usually made by Fused Deposition Modeling (FDM) 3D printers, such as the ones make by Bobby Rosenfield (https://www.apogeerockets.com/Rosenfield-Aerospace). The reason they are made this way is that they are quicker to 3D print because they have less material that has to be laid down during the build.

The 'flat top' version are easier to make using casting resin, mainly because they are easier to remove from the mold because they have less surface area on the top side. Those are the ones Apogee Components makes, because production time is a fraction of what it takes to build one on a 3D printer.



I would have thought that the split top version had more drag because I assumed there would be turbulent airflow coming out of the middle of the groove. But this is another case of where the results surprised me. The flat top version had 7.2% more drag compared to the split top. This goes to show you that assumptions are not always correct, and you have to do the experiments to verify them.

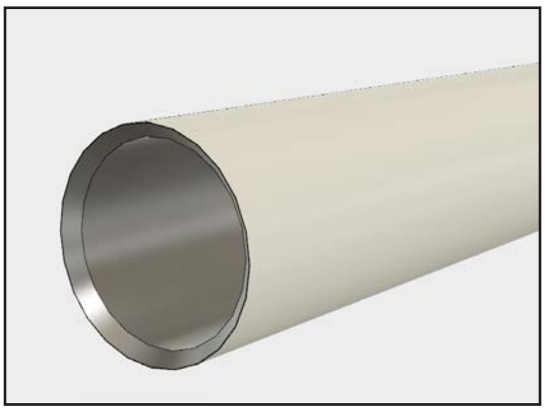
The next simulation was to see how much more drag a rail guide on a stand-off had versus a flush-mounted version. Apogee sells a lot of these stand-off rail guides to TARC teams for the 2016-1017 school year (https://www.apogeerockets.com/Building-Supplies/Launch-Lugs-Rail-Buttons/Rail-Buttons/Conformal-Standoff-Rail-Guide-BT60-BT70).



When running the CFD simulations, the result was as I expected. They did have a lot more drag, just like the rail button on a stand-off had more drag than a flush mounted rail button. Compared to the flush-mounted universal rail guide, the rail guides with a stand-off had 53.7% more drag.

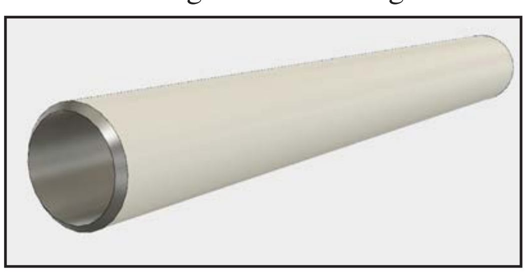
My next series of experiments went back to the standard launch lugs.

One problem that plagues my own rockets is spray paint clogging up the launch lug. To remove the this spay, I usually take a hobby knife and twist it inside the launch lug. What this effectively does is also chamfer the leading edge of the launch lug.



I ran the simulation to see how this compared to a standard launch lug. The result was another little surprise. By chamfering the inside edge on the front edge of the launch lug, it actually increase the drag force by 8.6% compared to a lug with just a flat leading edge.

This got me wondering. Would chamfering the outside edge have a similar effect?



So I ran that configuration too, and the result was a drastic reduction in the drag of the launch lug. The drag went from 0.180 lbs for the launch lug with a flat face on the leading edge, down to .061 lbs for the one where the outside edge was chamfered. This is a huge reduction in the drag force - just 1/3 of the drag!

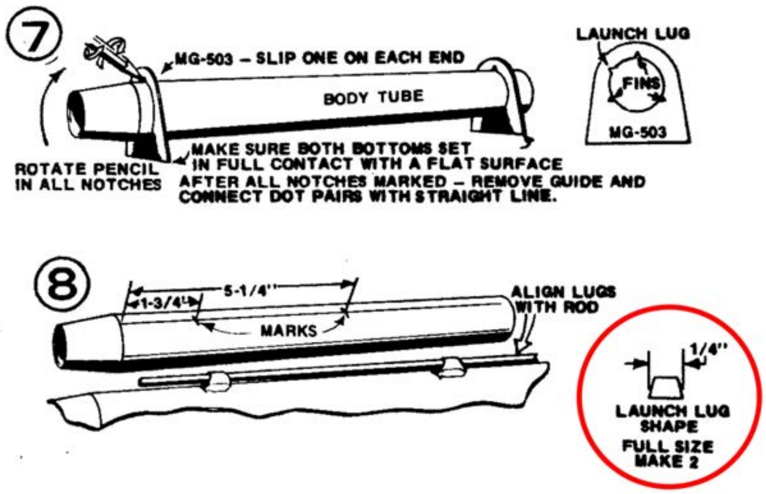
Clearly, the leading edge shape is the MOST important part of the launch lug. And it is such a simple modification that any modeler can make. Before you glue the lug to the side of your rocket, round off the front edge with some sandpaper! When you do that, you eliminate most of the drag of the launch lug.

This got me thinking about the rail buttons, so I wondered what kind of drag reduction could be achieved if you rounded off the top edge of the airfoiled rail button.

Again, the result was dramatic. Rounding off the edge of the airfoiled rail button immediately drops the drag 29.1%. And compared to the standard 1010 rail button, the drag drops 51.2% by just rounding over the top edge. It is not quite as good as a rectangular rail guide, but pretty close. The advantage comes if the rocket starts flying at an angle-of-attack (such as wobbleing during take-off).

Another simulation I ran was to see what happens if you have your airfoiled rail button crooked on your rocket. With a regular rail button, because it is circular, it will always be straight with respect to the air flow. But if the airfoiled rail button doesn’t swing freely on its screw post, it could be misaligned and be at some angle of attack. So I ran the simulation with the airfoiled rail button at a 5° angle-of-attack to the air stream. The result was an increase in drag, as I expected. But it was pretty minor, only an increase in drag of 4%. Modelers should take comfort in this, because even if your airfoiled rail button is at the wrong angle, the drag is still lower than a standard round rail button.

I was still intrigued by the result showing the leading edge of the launch lug as being the most important part of the drag picture. And that got me thinking of a kit that I enjoyed when I was younger. That kit was the Estes Astron Sprint (http://www.spacemodeling.org/jimz/k-49.htm). This kit was supposed to be optimized as a low-drag design. The launch lugs, in order to reduce drag were cut at an angle, so if you looked at them from the side, it would appear as a trapezoid.



The next CFD simulation ran was were I trimmed off the leading edge at a 45° angle. So the front opening of the tube sloped rearward.

Doing this dropped the drag compared to the standard "tube-type" launch lug by 34.2%. That's very significant.

Next, I trimmed the back edge off. It was easy... I just rotated the last launch lug 180° in the wind tunnel. So the front edge was squared off, and the back sloped back down toward the tube.

Doing this was shocking. The drag increased by 7.3% compared to a standard straight tube launch lug. This was totally unexpected. I would have thought that sloping that back edge toward the tube would have lowered the drag of the lug because it "looked steamlined." But according to the CFD simulation, the drag went up!

So I had to check the condition where both the leading and trailing edges were canted towards the middle, like the optimized Estes Sprint design.

The result was the drag was reduced by 15.7%. This is actually higher than the drag of just canting the leading edge and leaving the back edge squared off. Therefore the Estes Sprint launch lug is NOT optimized if you believe the CFD simulations. The back edge is in fact increasing the drag of the lug.

But that got me thinking… if a squared off trailing edge has less drag that one that slopes at a 45° angle down to the tube, what would happen if the angle was cut in the opposite direction - having an undercut at the trailing edge.

In the next simulation, which I called the "Swept Launch Lug" (where the side profile looks like a parallelogram), the drag did go down. It had 39.2% less drag than a conventional 1" long tube-type launch lug. Clearly this is a lot better than the Estes Sprint launch lug design.

Finally, one thing that I wondered was how does adding a fillet to the root edge affect the drag. In this CFD simulation, adding a glue fillet to the lug did in fact reduce the drag. Compared to the standard 1/8” X 1” long launch lug, the drag of the filleted lug was 3.9% lower.

Optimizing the launch lug

From the various configuration tests I ran in the software, I wanted to see if I could optimize the standard 1/8” diameter launch lug. Basically, my hypothesis was that the lug should be:

- Longer in length
- External chamfer (or rounded) on the leading edge
- Swept back on both the leading and trailing edges
- Filleted along the root edge where it is glued to the rocket

Running the CFD simulation, this configuration did in fact have the lowest drag and the drag coefficient. Compared to the standard 1/8” diameter X 1” long lug, which had a drag force of 0.051 lbs and C_d of 0.60, the optimized lug generated 0.026 lbs of drag, and a C_d value of 0.24. In layman’s terms, there was a reduction of 49% drag by optimizing the shape of the lug.

The Conclusions Drawn

The purpose of any of the launch guides (such as the launch lug, the rail button, or rail guides), is to make it more convenient to safely launch a model rocket. In reality, we could launch without them by using other guidance methods, such as piston launchers, tower launchers, or fly-away-rail guides. But those other methods are more complex to set up at the launch site. So we use launch lugs, rail buttons and rail guides to make launching more convenient, even though we know they will add more drag to the rocket.

Therefore, this exercise in finding the drag of launch guides, was more of a way of putting a price on that convenience.

The incorrect conclusion is that some may conclude that there is an optimized shape for a rail guide. In fact, the optimized shape is no shape at all - it needs to be removed completely.

What I found by doing this R&D project is that the available CFD tools such as Flow Design can be used to determine the drag of a launch lug. However, we still don't know how accurate these estimations are. Without validation, the estimations in this report are suspect.

With that caveat being said, I discovered that the standard estimation methods we have been using for launch lug drag may be completely wrong — if you can believe the CFD results. For example, the standard assumption that the shorter the launch lug, the lower the drag it has does not match the CFD simulations. In the CFD simulations, a longer launch lug has far less drag than a shorter one. Some of the other results were also pretty surprising, such that a bigger rail guide has less drag than a small launch button.

Further work that would clarify or extend the results obtained

The big unknown is if the simulations match real world results. In order to get drag forces large enough to be computed, the models had be be enlarged 10 times their original size. But that changes the Reynolds number of the models and the flow situation. The question I have is do the 10X models actually represent what is going on for a real launch lug that is much smaller? It is hard to say, because validating the results may prove impossible because the drag forces are so tiny. The force measurement system may not be capable of measuring these forces.

It may be possible to validate the CFD results with other CFD programs in the future. There may be low priced programs available in the future that could calculate the tiny forces on the small models we use in model rocketry. I currently do not know of any such program, but readers of this report might.

One thing that I didn't have time to do was run a few other simulations that could provide additional data. Simulations that could easily be run in the future include:

1.) Longer launch lugs - I stopped at 2 inches long for a 1/8" diameter launch lug. Increasing the length could be used to determine how long a truly optimized lug should be.
2.) Fillet Diameter - I only chose one fillet diameter. It would be interesting to see what is the optimized diameter.
3.) Airfoiled rail guide optimization - I would have like to have tried to sweep the leading and trailing edges of this rail button to see if it could be optimized too.
4.) The other effect that can be studied using CFD is how two lugs on a straight line (a typical arrangement in rocketry) affect the overall drag. The general thought after performing this study is that a single long launch lug would be better than two smaller lugs that are spaced apart on the rocket. But is this really the case? I don't know until the simulations are actually performed.
5.) Location of the launch lug - Do you see a reduction in drag if you attach it along a fin root? Or does that cause other drag problems? This could be easily studied with the CFD software.
6.) Does putting a turbulator in front of the launch lug reduce the drag?
7.) What is the result of a rail guide at an angle of attack versus a airfoiled rail button at a comparable angle?