APR Performance
APR004 Wing Profile
CFD Analysis

NOTES AND IMAGES

Andrew Brilliant
FXMD Aerodynamics Japan Office
Document number: JP. AMB.2011.6.17.002
Last revision: JP. AMB.2011.6.24.003

Purpose

This document contains images and notes from CFD design and testing of the APR004 dual element wing.

FXMD Aerodynamics was awarded the task of designing a wing to achieve extreme performance from a compact size, dual element package (250mm main plane, 100mm flap). Design freedom was granted for the elements, their placement as well as that of the end plates. The purpose of this wing arrangement was to become a universal aerodynamic upgrade assembly for vehicles marketed at tuners. As such, adaptability to various applications required a large adjustment range, from high efficiency/low drag to extreme down force with maximum possible efficiency across the entire aerodynamic range. The aim was to exceed the performance of every product in the market segment at any adjustment and still retain a budget minded price point.

In order to reduce the cost of production, the adjustability was to be limited to the flap only; as such, the main plane would be in a fixed position. The flap thereby, would be adjustable through a single pivot point, making the flap design the most critical component.

Use of two-dimensional CFD to analyze potential designs

Various wing shapes were evaluated using 2D CFD before the final candidates were tested in 3D. 2D uses significantly less computational processing power, so many designs can be analyzed quickly. However, the results are less accurate. Combining 2D and 3D allowed for more than a hundred basic shapes to be analyzed efficiently before specific candidates were selected for more expensive and time consuming 3D methods.

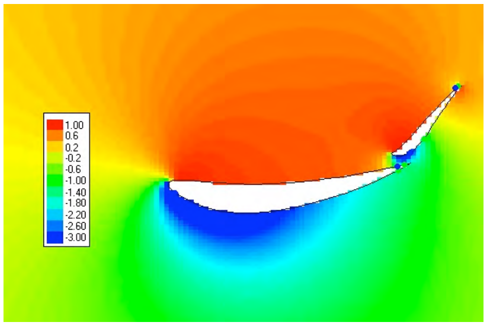


Figure 1: 2D CFD of multi element airfoils

The nose profile of the flap was an area of extreme interest. Not only in terms of the interaction with the main plane but in terms of slot gap stability through the adjustment range. The details of this design feature were able to greatly reduce the complexity of hardware to adjust the flap.

After the elements were finalized, their placement was optimized firstly in 2D, through pressure distributions and flow streamlines in order to help deliver us a “best guess” placement for the application of 3D development.

A proper application of “slot-gap” energizes the flow of air and prevents stall behind the flap. The result is a much higher total camber of the wing package than would be possible with a single element. The resulting “wake fill” reduces drag and further contributes to the overall efficiency of the package.

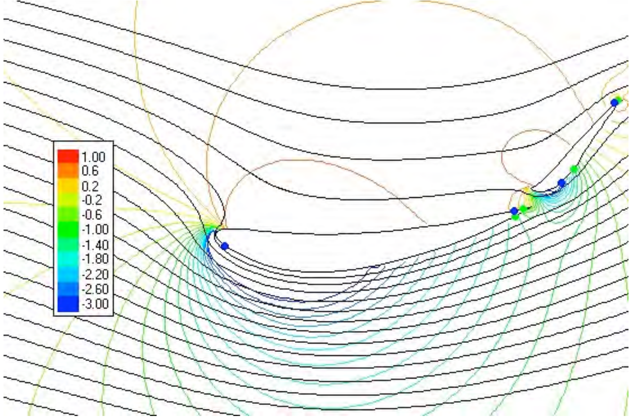


Figure 2: Flow streamlines colored by pressure for flap placement analysis

Validation in three dimensions

The switch to 3D methodology proved effective, as even the initial 3D runs showed promise. The main plane achieved an excellent pressure distribution on both the upper and lower surfaces. Maximizing these surface areas in tandem utilizes its size effectively and achieves forces typical of a larger wing.

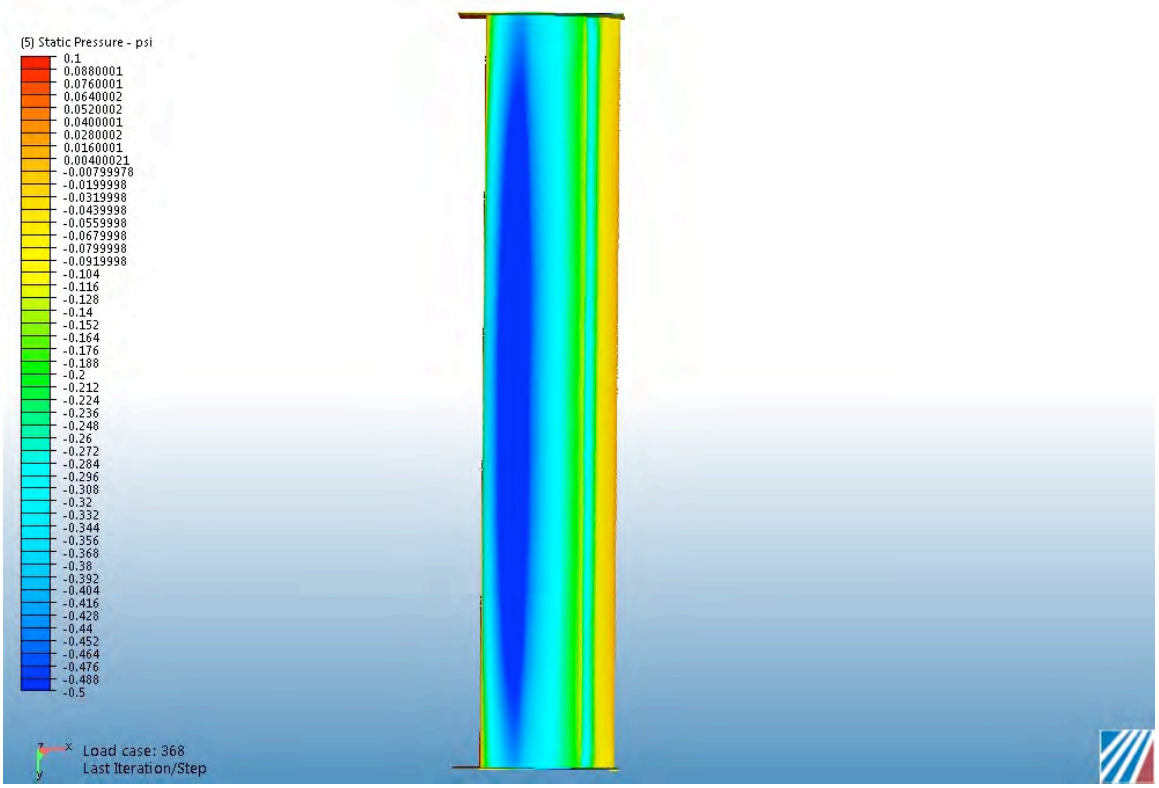


Figure 3: Under-side pressure distribution of main plane

Main plane pressure distribution and its effect on flap placement

Flap placement is often a compromise as many different values for down force and efficiency can be achieved even with the same two elements. Therefore, the flap position is pivotal in its interaction with the main plane and much thought needed to be given toward the regions of the wing's adjustment range that required the highest efficiency.

The flow fields are not uniform across the wing span due to 3D effects such as tip vortices, which required flap placement to be re-optimized in 3D. The slot gaps were adjusted again by about 2mm from 2D optimums and this resulted in an 8% improvement in the wing performance.

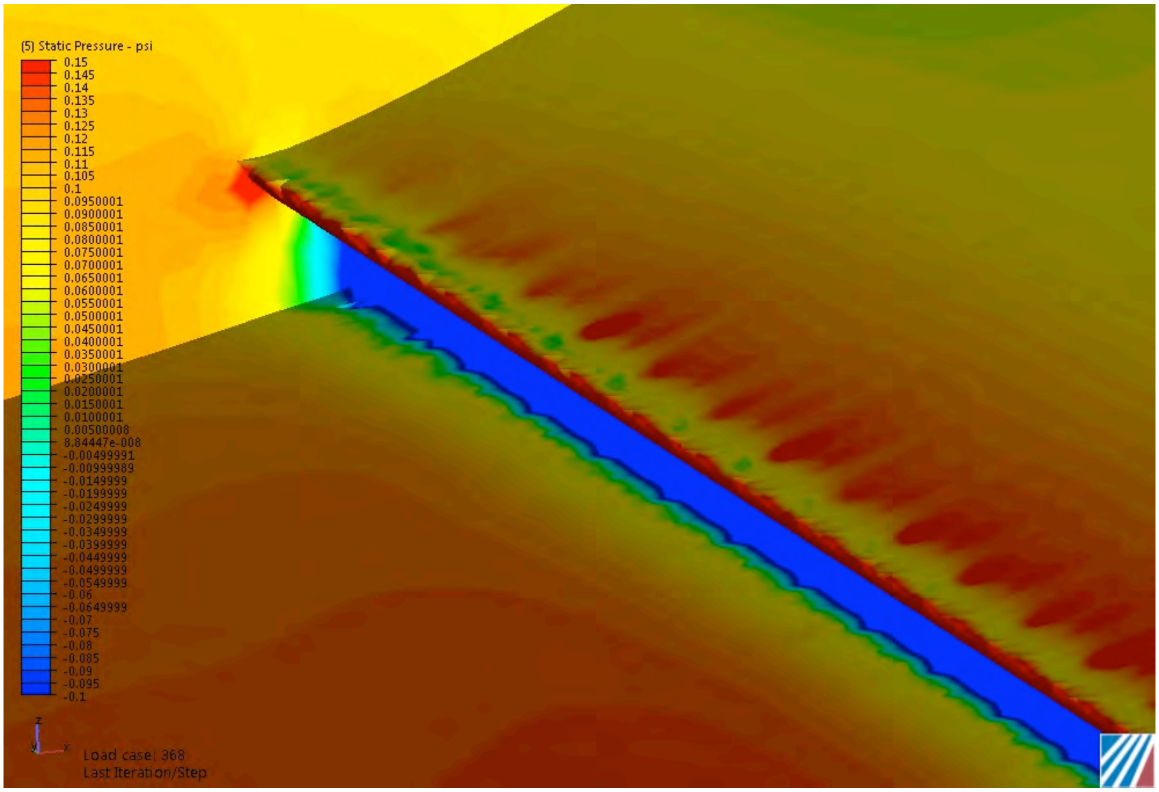


Figure 4: Flap effect on main plane pressure at its trailing edge, near end plates.

In testing, the nose profile proved effective and the design was thus finalized. The main plane was a modified 4-digit NACA profile and the flap was designed from scratch.

End plate optimization

The final task was the end plate optimization, which proved a challenge as it required methods of adjustment limiting the options for end plate design since it had to accommodate a wing of both varying height and length. Again, a tuned configuration had to be selected and compromises made for other points in the adjustment range. After consulting with the staff at APR, it was decided upon to target a larger total down force number, as the efficiency had already surpassed expectations. A large number of end plate configurations were then evaluated throughout the adjustment range of the wing.

Performance goals achieved

The result of this design process achieved all targets set. In low down force configuration, more than 8:1 Lift/Drag was achieved while producing 317 pounds of down force at 120mph. At 160mph and minimum angle of attack, nearly 8.8:1 Lift/Drag was achieved for 565lbf. This drag penalty should be exceptionally low for a car targeting high speeds such as standing mile or land speed competitions. On the opposite end of adjustment range, the wing is adaptable to an autocross application. At 52-degree flap angle, it produces 1115lbf at 120mph and 1650lbf at 160mph for a 3.6:1 L/D. Please see addendum for a full table of results.

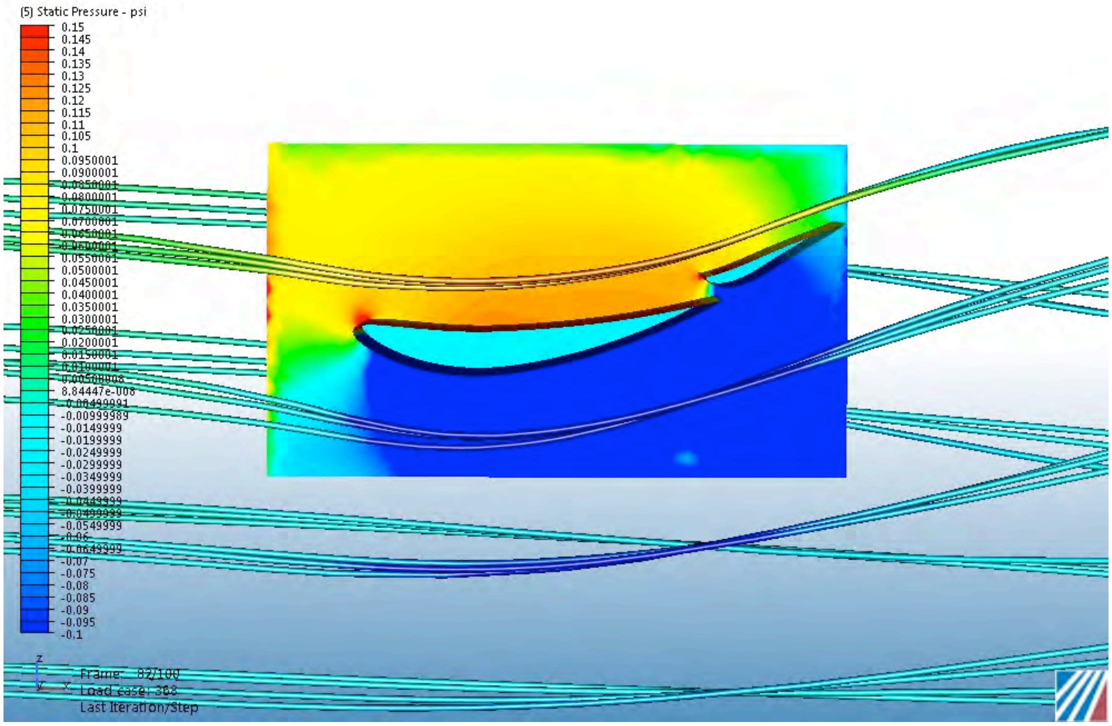


Figure 4: End plate optimization using 3D CFD. Flow streamlines are also used to tune end plate dimensions in order to gain favorable interactions between tip vortices and aerodynamic surfaces.

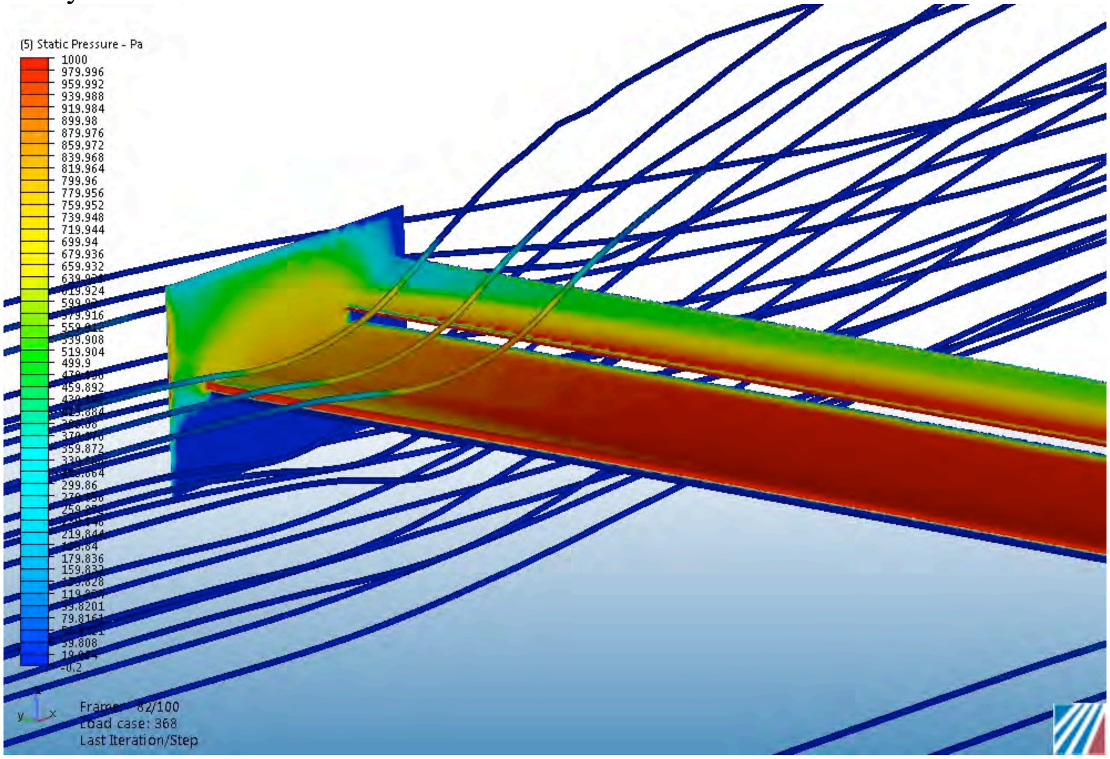


Figure 5: Tip vortex formation around an optimized end plate

As this was to be a wing suitable for universal applications, optimizing it for use on any individual car would have little value to its users. The decision was then made to design using free air stream methods and evaluate differences in flow fields on a variety of vehicle models. Generic bodies were used for this final "on car" testing. Three simplified vehicle models were selected with various shapes, specifically a variety of angles to the rear deck and hatch. The shapes selected included a hatchback model, a four door with a high angle rear deck and a streamlined model.

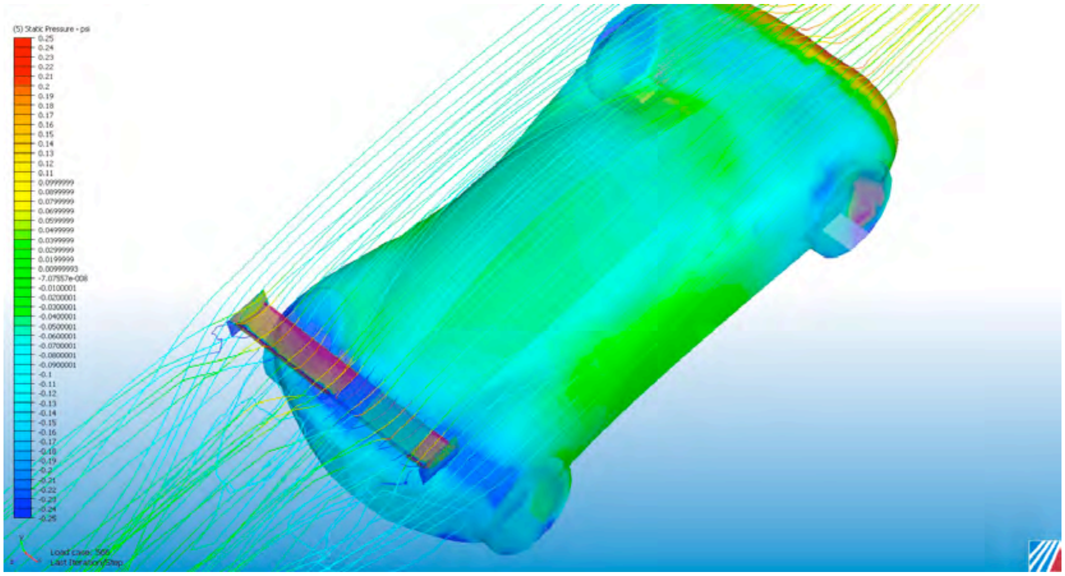


Figure 6 : Streamlined body. Pressure traces shown

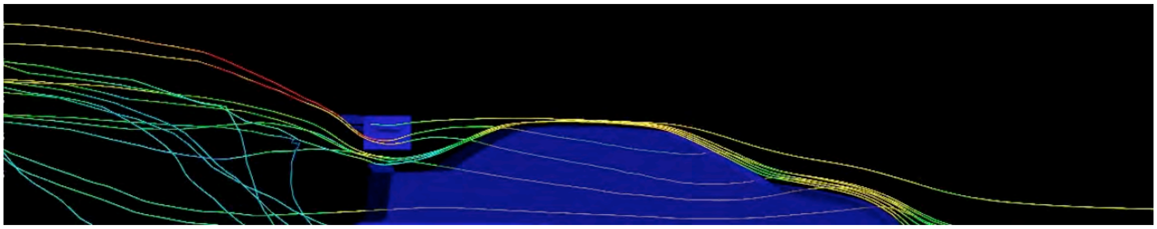


Figure 7: Velocity trace over rear deck of a Mitsubishi Lancer Evolution simplified model

APR WING CFD DATA PROFILE: APR004 DUAL ELEMENT 2011.4.17

All values are pound force (lbf)

Fz = Lift Fx = Drag L/D = Lift/Drag ratio

Positive lift values are downforce

main plane locked at 4 degrees

Prepared by: **FXMD Aerodynamics**

Flap AOA	Fz	Fx	L/D	Speed
10	140.44	17.60	7.98	80
10	317.28	39.40	8.05	120
10	565.20	64.40	8.78	160
20	264.53	43.43	6.09	80
20	598.76	94.64	6.33	120
20	1063.81	168.58	6.31	160
30	276.05	47.45	5.82	80
30	627.58	107.58	5.83	120
30	1168.17	227.46	4.93	160
40	325.56	67.24	4.84	80
40	737.86	152.51	4.84	120
40	1262.24	285.23	4.43	160
52	495.16	137.66	3.60	80
52	1115.20	315.28	3.54	120
52	1650.65	448.33	3.68	160

Speed tables

80MPH

flap AOA		10	20	30	40	52
Drag		17.60	43.43	47.45	67.24	137.66
Downforce		140.44	264.53	276.05	325.56	495.16

120mph

flap AOA		10	20	30	40	52
Drag		39.40	94.64	107.58	152.51	315.28
Downforce		317.28	598.76	627.58	737.86	1262.24

160mph

flap AOA		10	20	30	40	52
Drag		64.40	168.58	227.46	285.23	448.33
Downforce		565.20	1063.81	1168.17	1262.24	1650.65

Efficiency by Speed

flap AOA		10	20	30	40	52
80 MPH		7.98	6.09	5.82	4.84	3.60
120 MPH		8.05	6.33	5.83	4.84	3.54
160 MPH		8.78	6.31	4.93	4.43	3.68

Efficiency by AOA

		80 MPH	120 MPH	160 MPH
10 AOA		7.98	8.05	8.78
20 AOA		6.09	6.33	6.31
30 AOA		5.82	5.83	5.89
40 AOA		4.84	4.84	4.43
52 AOA		3.60	3.54	3.68

Downforce

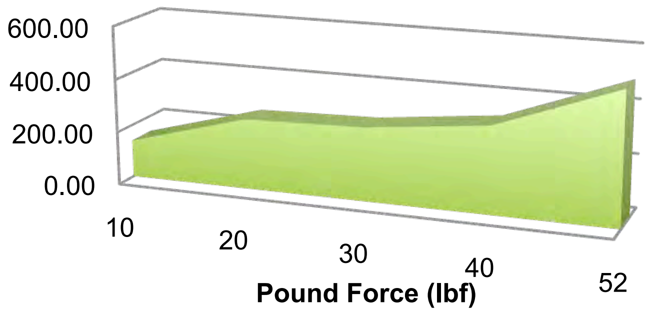
		80 MPH	120 MPH	160 MPH
10 AOA		140.44	317.28	565.20
20 AOA		264.53	598.76	1063.81
30 AOA		276.05	627.58	1168.17
40 AOA		325.56	737.86	1262.24
52 AOA		495.16	1115.20	1650.65

Drag

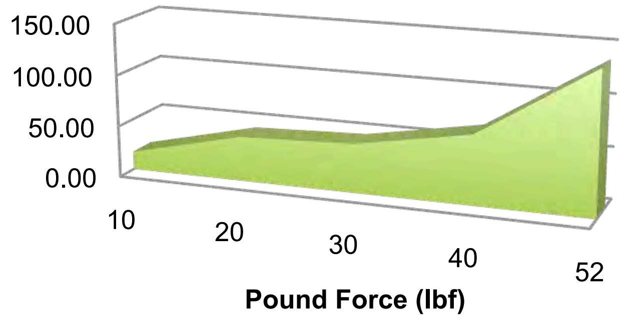
		80 MPH	120 MPH	160 MPH
10 AOA		17.60	39.40	64.40
20 AOA		43.43	94.64	168.58
30 AOA		47.45	107.58	227.46
40 AOA		67.24	152.51	285.23
52 AOA		137.66	315.28	448.33

Wing forces

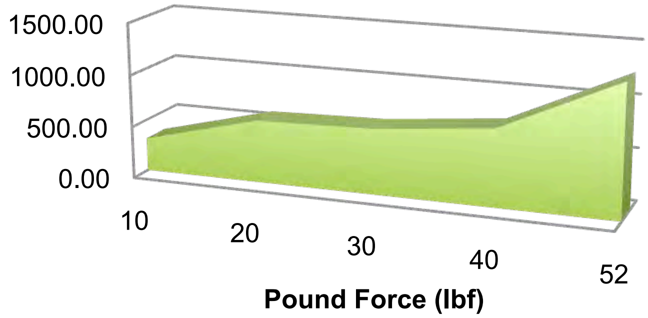
80MPH Downforce



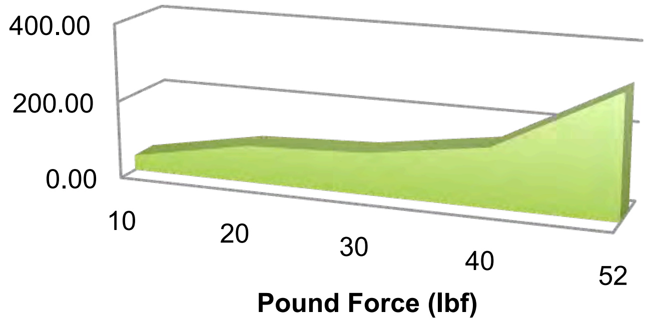
80MPH Drag



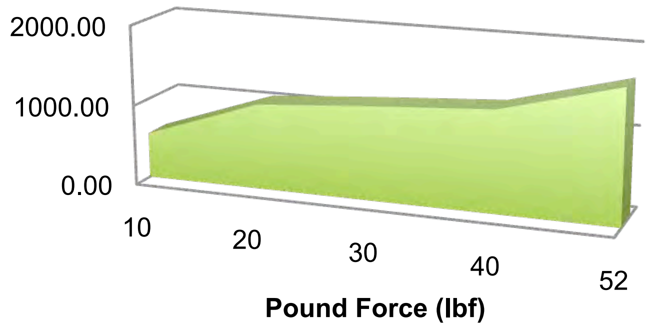
120MPH Downforce



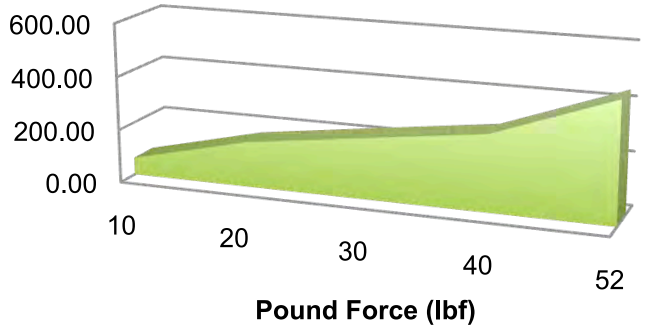
120MPH Drag

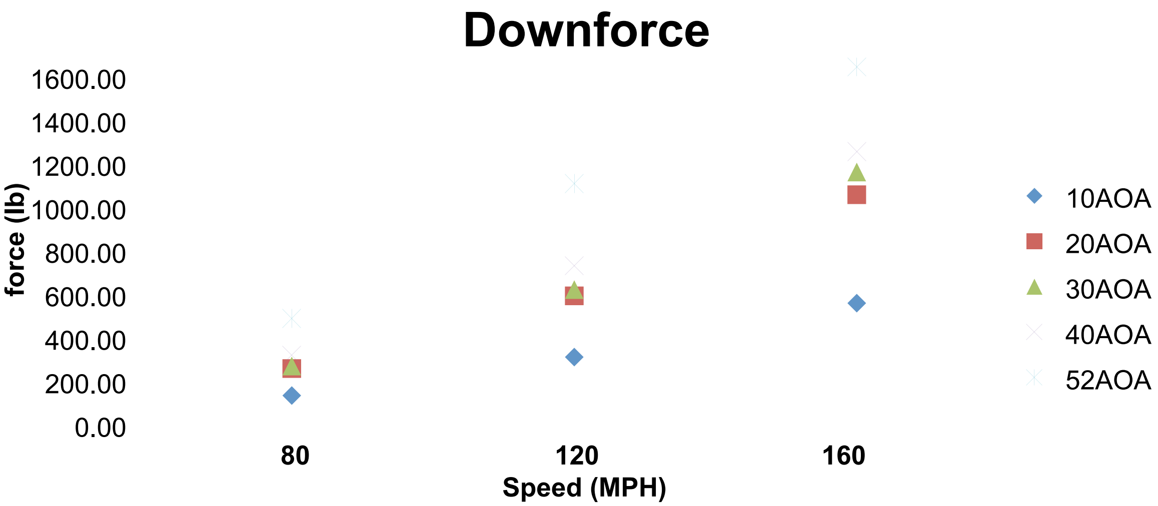


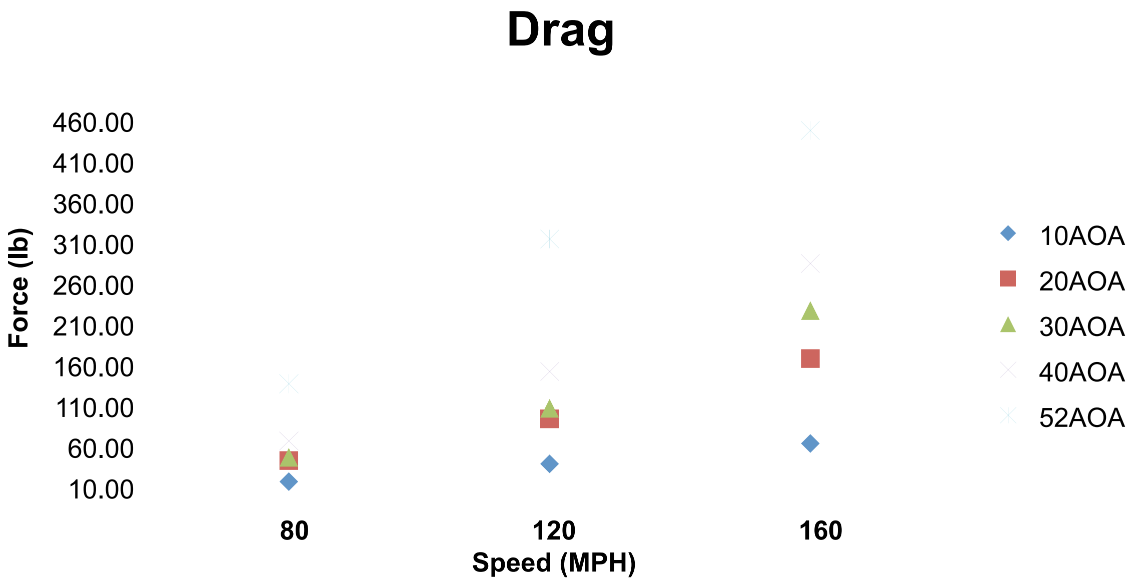
160MPH Downforce



160MPH Drag




Downforce
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
force (lb)
80
120
160
Speed (MPH)
10AOA
20AOA
30AOA
40AOA
52AOA


Drag
460.00
410.00
360.00
310.00
260.00
210.00
160.00
110.00
60.00
10.00
Force (lb)
80
120
160
Speed (MPH)
10AOA
20AOA
30AOA
40AOA
52AOA


Lift/Drag Ratio
9.00
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
80
120
160
Speed (MPH)
10AOA
20AOA
30AOA
40AOA
52AOA