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...IS THIS THE ULTIMATE TEST FOR A WING?

By Chris Pickering

Speed: it's the one thing that motorsport is all about really. Ultimately, for all the ground-breaking science and technology that goes into it, the purpose of racing is to cover ground faster than the next man. And if he happens to be in a Top Fuel dragster this puts you into a whole world of superlatives. To those – like me – used to road racing, the headline figures generated by dragsters are borderline surreal.

A typical NHRA (National Hot Rod Association) Top Fuel car crosses the line at around 325 mph (523 kph) – nearly 100 mph quicker than the fastest speed yet recorded in a Formula One race. But even more impressive is the way it gets there. Top Fuellers can accelerate at over 5 g, passing the 100 mph (160 kph) mark in 0.7 seconds and exceeding 280 mph in a space of 660 feet (200 metres). True, they've got 8,000 or so horsepower to play with and corners aren't really an issue, but the performance is, nonetheless, staggering.

In fact, I'm still trying to wrap my head around the figures while Craig McCarthy of Aerodine Composites tells me about the new front and rear wings that the company has developed for this insane sport. There's something faintly amusing about the degree of nonchalance he applies to it. "These cars are reaching about 324 mph at the end of the run, but we assumed a speed of 300 mph for a lot of the calculations, because this is the last zone where the downforce is really important to carry the car through to the finish," he comments with the sort of relaxed enthusiasm that makes it all sound routine.

At this speed the rear wing alone produces about 5,500 lbs of downforce and generates around 1,000 lbs of drag. Its primary job is to create enough traction to transmit the vast torque developed by the supercharged Chrysler Hemi-derived V8. Even at 300-odd miles an hour the tyres are spinning slightly and the rear downforce is an important part of the setup procedure. Beyond a certain level of slip the grip breaks down and the tyres go into an oscillation known as tyre shake. The trick is to provide enough downforce to prevent this, without inducing too much additional drag, but it's not always easy.

"If you've got a change of surface, say from concrete to asphalt, part way down the strip it can trigger a loss of traction," McCarthy explains. "You also get little bumps and imperfections on each track, and it's not uncommon to get patches of oil laid down if the car before has had an engine failure. In any of these cases the crew chief may choose a more conservative setup with more wing on the car to provide more downforce."

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where they have to increase it to counter the reduced air density. And, likewise, the development of the wings themselves has traditionally progressed at quite a leisurely rate, with the NHRA, the sport's governing body, keeping a careful eye on costs. It wasn't an area that had seen much new blood for a while, but that all changed with the arrival of Aerodine Composites.

**SURPRISING CFD RESULTS**

"Until recently the market only had one source for wings. It's a fairly small operation here in the States that wasn't able to keep up with demand and we'd been approached several times to produce wings for the sport," McCarthy recounts. "The market has always been pretty small commercially, and it's never going to be a huge money-making operation, but eventually we decided to have a go at a quick CFD study - just to get an idea of how much potential there was to improve upon the current solution at a sensible cost. We were surprised at what we found out."

Although it was immediately apparent that the potential existed to improve upon the previous wing designs, the Aerodine Composites engineers didn't have it all their own way. In order to get major components such as wings or fuel injectors admitted into NHRA Top Fuel drag racing you first have to seek approval from the association's technical committee. The idea behind this isn't to enforce a spec series, but rather to keep costs under control by ensuring that no one product can become a costly must-have.

With this in mind they had to tread carefully, but the engineers sought to come up with a solution that offered useful gains over the old design without contravening the NHRA guidelines. Specifically, it needed to be a three-element design (featuring a main plane and two flaps) that fell within stringent surface area tolerances and passed a test for structural deflection.

"As close to freestream as you'll ever get in practical aerodynamics"
Having come up with an initial proposal for a rear wing they carried out a CFD study and took the results to the technical committee. Despite fulfilling the basic criteria there was still a fear that the Aerodine Composites design would be too radical, McCarthy recounts: "The NHRA technical committee thought the performance difference would be too big a step up from the current designs, particularly given that we were proposing to come in with Al-Anabi Racing, which is one of the biggest teams in the sport. The drag figure, in particular, was a lot lower than before, so we were asked to come back with something closer to the current wings."

With the aero data he'd taken from the study of the existing wing as a template, McCarthy set about designing a compromise that would tone down the initial proposal yet still offer improved drag characteristics over those currently on the market. And it turned out to be quite a drastic redesign: the flaps and endplates remained the same, but the main element had to be totally remodelled, sending the project back to the drawing board (or rather the computer).

The entire development process was carried out with CFD. This helped to control the costs compared to wind tunnel testing, and in this instance McCarthy believes it was every bit as valid. Because the target figures had been generated by a CFD model using the same techniques any small errors with the correlation would have been the same for both tests. "In this case we could rely on comparative results even without physical tests to validate them," he comments. "It's actually very much the same situation you get in a wind tunnel. You can compare them to one another, but experimental results can't be guaranteed to correlate with real world findings there either."

In both studies he modelled the wing in isolation. It sits so far up in the air that McCarthy reckons it's about as close to freestream as you'll ever get in practical aerodynamics. Even without modelling the rest of the car's geometry, the runtime of the simulation was between 12 and 14 hours for each study, and the computing power required to model the rest of the car would have forced Aerodine Composites to outsource the work. This would have added cost and complexity to the project, which, given the near-ideal airstream meeting the wing, was deemed unnecessary.

One of the primary issues that McCarthy had identified with the existing design was the generation of large, drag-inducing vortices at the rear. "If the humidity is high enough you can actually see them spiralling off the current wings with the naked eye — particularly at high speed," he explains. A lot of work went into remodelling the endplate design to minimise these, and it's said to account for a large part of the drag reduction, which totals around 11 per cent over the current offerings.

Once the work was progressing on the rear wing, Aerodine Composites began looking at a solution for the front end, and here it
encountered one of the unique challenges posed by dragsters. As the cars launch off the line, the torque reaction to the engine causes them to twist noticeably along their axis. In fact, so severe is the level of flex that it can actually pull one side of the wing out of ground effect, while pushing the other further down. To compound matters, while the wing is 62.5 inches wide, it’s mounted on centres just two inches wide, which means that a small oscillation can easily magnify itself. Apparently it’s not unknown for the cars to rub off the bottom of the endplates over the course of a few runs for precisely this reason.

The problem this poses is partly an aerodynamic one – ensuring the wing will remain stable over a range of attitudes – but also a structural one. Part of the problem, McCarthy believes, is that the natural frequency of previous designs has been close to that of the torsional oscillations which occur along the chassis. When the two coincide they effectively go into resonance, making matters far worse. One of the ways he sought to address that was by careful design of the wing’s internal structure. Altering the properties of the spar within it, McCarthy could change its natural frequency and push it away from the harmonics of the chassis.

The same structural idiosyncrasy leads to another very strange effect: dragsters are perhaps the only cars to push the front wing down during acceleration. The back end squats to a certain extent, but, rather than pitching the front skywards, the flexibility of the chassis simply allows it to bow in an arc, pushing the middle part of the car into the air and angling the nose down. Unfortunately this, along with the rising airspeed, tends to increase the level of downforce along the run, when arguably you want it to bleed off. Meanwhile, the same effect increases the rear wing’s angle of attack, upping the downforce. Or at least it does until tyre shake sets in, at which point the expanding diameter of the rear wheel can push the back end up, reducing the rear wing angle; all of which means the wing has to be designed to operate consistently over a wide range of angles. Similarly, McCarthy wanted to provide a greater degree of adjustability than the teams could get with the current wings.

"Typically the teams used to have only two or three different positions – relative to the main plane – in which they could run their flaps, but our wing has eight,” he explains. “We’re supplying them with aero data for those eight options as well as documenting the effect of rotating the whole assembly through a range of angles, so the teams have a lot more to work with. Knowing we were going to provide that level of adjustment it was important to find that sweet spot whereupon the wing would function across the whole range. It turned out this was a fairly difficult thing to do.”

With a three-element wing the top flap has a very steep angle of inclination, McCarthy explains, which means it’s always on the verge of simply turning into a large spoiler. Aerodine Composites wanted to make sure there was consistent flow across all three elements of the wing, but early on in the testing it discovered the top flap was liable to go into stall.

“IT’s really all about positioning,” McCarthy explains. “As you move the various elements of the wing you end up changing the gaps between them, and they can become ineffective if you go too far in either direction.” And yet, with careful

While the rear wing is all about brute force and downforce, the front requires far more finesse"
control of this, he believes he's found a good balance, that allows all three elements to function in a large variety of different attitudes and environmental conditions.

One thing you can't overcome, however, is the savage environment the wing has to operate in. The shock waves from the header pulses are brutal, contributing something like 800 lbs of downforce simply from the thrust as they’re fired upwards out of the exhaust. Unburnt nitromethane flash fires when it encounters the oxygen in the air, sending sheets of flame, which reach nearly 1,800°F (980°C) by the end of the run, towards the wing. And that's assuming all goes well. The superchargers are driven by fabric belts, which have a habit of detaching themselves and hitting the leading edge of the rear wing on the way; plus it's quite common for the timing cones at the side of the track to be collected if the cars get out of shape. Both are relatively minor issues on their own, but ones that could become disastrous. "At 324 mph anything becomes a projectile," comments McCarthy. "The risk is that a small impact to the front of the wing could propagate through the structure of the wing to cause a massive failure and a sudden loss of downforce."

**STRUCTURAL CHALLENGE**

By far the biggest structural challenge is simply the vibration, however. When the car goes into heavy tyre shake it can have catastrophic results for both the car and driver. In 2007 Funny Car racer Eric Medlen sustained a fatal brain trauma caused by the force of oscillation when his car went into tyre shake. A report later concluded that the deflating tyre had led to an oscillation of 1.8 inches, exerting a force of over 40,000 pounds (20 tons). And while the driver is clearly the most important component in the car, the sheer magnitude of the vibration is even greater for the wing, which sits on top of a seven-foot tall pylon, acting like a giant lever arm.

Aerodine Composites uses a blend of two different types of carbon fibre in the designs: Toray BOO 3k bidirectional prepreg fabric, which has a lower tensile strength but rather more flexibility, and a T700 material that's stronger but ultimately more brittle. All the surface plies that need to be robust are manufactured from the T300 material, but the load-bearing inner plies are made from Toray T700 unidirectional tape. Kevlar, meanwhile, is used extensively, particularly in the leading edge, where it protects against impacts and serves to hold everything together in the event of a failure.

Much of the structure is actually metallic. The mounts that come out the wing are made from aircraft-grade aluminium and they sit on a chrome-moly steel tree structure, while the spars are a mixture of carbon and aluminium, paired with carbon fibre ribs.

This rather eclectic mix of materials performs well structurally, but it does make the task of stress analysis somewhat more complex. "There aren't many companies that can actually model composite structures effectively and each one has its own approach," says McCarthy. "Where we have an advantage is that we can manufacture and test the products in-house to validate the FEA results." Nonetheless, he maintains it's not a black art: "Basic shell modelling works wonders for composites, but you do need to give it the appropriate amount of input ... We're not dealing with isotropic materials here at all; they display totally different properties in different directions, so you have to know exactly how they behave – that's the important bit."

Aerodine Composites produced two CAD models of the wing. The first featured all the appropriate material thicknesses and representative gaps for adhesive, to be
used as a guide for manufacturing purposes. The second, for FEA modelling, represented the aluminium components as they would be manufactured, but approximated the composites to a series of mid-plane surfaces. This meant McCarthy could model the individual plies separately and assign different FEA properties to each one.

"There are some FEA packages out there that will take your ready-to-manufacture surface and apply a composite laminate to it, but I prefer the control you get from modelling the plies separately," he comments. "It becomes extremely important when you have a mixture of different materials, and particularly where you choose to reinforce certain areas (like the leading edge of the wing). We have quite a lot of additional plies to consider on the leading edge, including the Kevlar ones."

After another anxious meeting with the NHRA the rear wing was given the go-ahead. The first example was passed to the Al-Anabi team, along with extensive aero data generated by the CFD simulations.

"When the team first began testing we were already able to supply the relevant aero data and suggest a starting point for the front wing angle," McCarthy recounts. "They went out with those settings and the driver loved it on the first pass. We were ecstatic about that, because the wing was designed exclusively in CFD and we never backed it up with any wind tunnel testing. That effectively validated all our work."

It was with this wing that Larry Dixon won the 2010 Full Throttle Drag Racing Series, and yet the process continues. The next step has been to finalise the design and production of the front wing. This uses very much the same principles and construction as the rear wing and builds on the test results collected in 2010. On its first outing with both wings, at the NHRA Winternationals event in Pomona, California in February, the car established a new national ET record, covering the 1,000-foot course in 3.77 seconds and crossing the line at 327.03 mph. With that, it seems, McCarthy and his colleagues have achieved what they set out to do, but the quest for speed goes on.