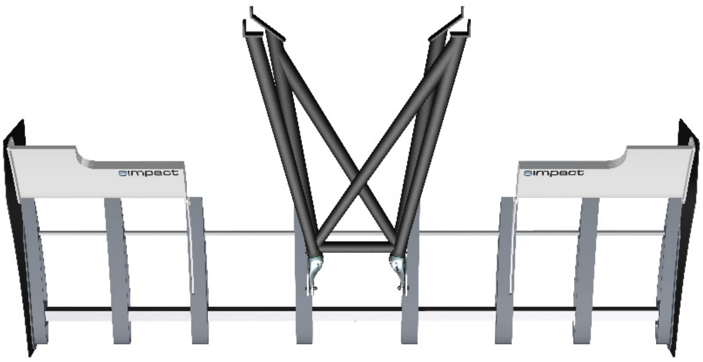
Case Study

ALM Innovation in British Hillclimbing

How fast can you get to the top of a hill in a single seater racing car? Sounds pretty simple doesn't it but at the top of this game, British Hillclimbing is a fiercely competitive form of motorsport where competitors seek out even the smallest advantages that can make all the difference between winning and losing. Not forgetting driver ability and horsepower, key to achieving a fast time across the line is to take as little weight up the hill with you as possible.

In a collaboration between Midlands SME, Simpact Engineering Ltd and WMG (Warwick University) project partners have demonstrated significant innovation at this level of motorsport by the combined application of their respective skills and expertise has produced a new front wing and support structure which is almost half the weight of the original design - that's more than 2kg less weight to take up the hill. This is a delta which the driver will really notice.

This technology demonstrator is making big waves in this very niche form of motorsport and shows what is possible when two innovative companies collaborate. This case study describes how they did it.



Technology Overview

Simpact and WMG bring their skills together in a very effective combination; Simpact in the design and verification of lightweight structures (CAD & CAE) and WMG in 3D printing otherwise known as Additive Layer Manufacturing (ALM).

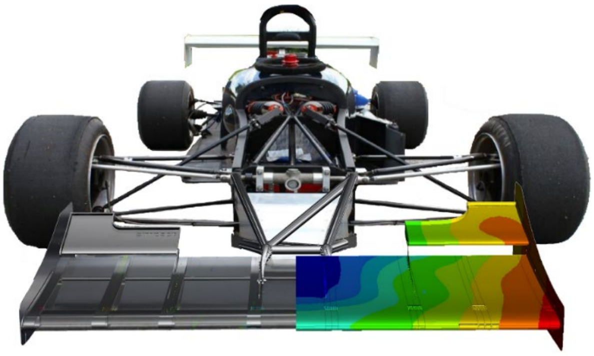
WMG - Additive Layer Manufacturing (ALM)

Most people are already aware of the significant advantages that this digital technology brings by being able to produce top quality parts from CAD data fully automatically on very short lead times with no need for any tooling whatsoever. The process builds the parts up layer by layer which enables the creation of extremely complex geometries such as freeform surfaces, deep grooves and three-dimensional cooling channels. This technology has evolved rapidly with the increasing need for more complex, higher performing products at lower cost, particularly in the high value manufacturing sector.

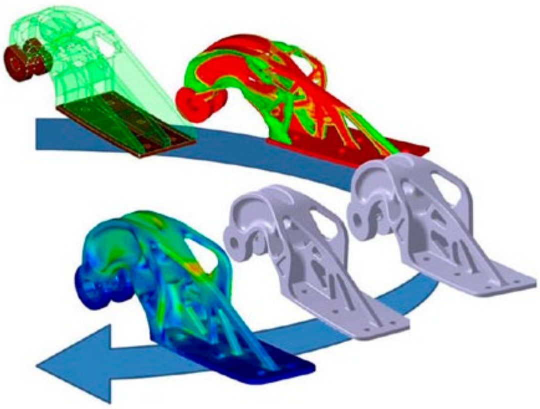
Metal ALM is a relatively new development and currently very expensive compared to printing in say ABS. Costs are set to tumble with increasing uptake and the EOSINT M280 system based at WMG (shown above) is the leading system on the market for the additive manufacturing of metal components. The Direct Metal Laser Sintering (DMLS) process builds the parts up layer by layer by melting fine metal powder with a high power laser beam.

ALM technology is particularly well matched to modern product development and the use of CAE optimisation techniques as these can be used to derive the best and most economical use of material completely free from manufacturing constraints. This technology is used to create components of the front wing assembly that require geometric consistency, component strength and ones that would otherwise take a reasonable amount of time to make (by hand) and require an investment in tooling.

Simpact – Computer Aided Engineering (CAE)



Simpact is a high quality Computer Aided Engineering (CAE) consultancy who's core business activity is the design, development and engineering of bespoke safety solutions which offer protection from impact loading. CAE is a broad term and covers several tools such as Finite Element Analysis (FEA) which is a method to analyse the structural response of systems to anticipated loadcases before the part is manufactured. Providing accurate geometry and material properties are available, this approach allows for the development of a highly optimised structure and is eliminates the needs for physical prototypes.



The software of choice for this project was Altair HyperWorks. This includes the Optistruct and RADIOSS software suitable for the analysis of linear and non-linear (crash) loadcases respectively.

Optimisation routines within Optistruct allowed us to generate innovative concept design proposals based on user-defined design space and performance targets. This was used for the critical load bearing metal parts of the front wing assembly that were made using metal ALM and had no manufacturing constraints.

Although impact loading was an important loadcase for analysis, the performance of the wing to normal in-service loading was the focus of the CAE analysis.

The following 5 loadcases were analysed;

1. Aerodynamic loading – evenly distributed (-z)
2. 3g bump (-z)
3. 3g rear (-y)
4. Point loading on wing tip (-z +z), (-x +x), (-y, +y)
5. Impact loading (full frontal rigid wall and 45deg kerb impact at 90mph)

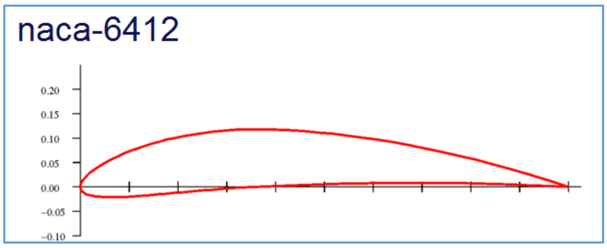
The outputs of CAE models require targets to quantify performance and the ambitious target was set to deliver the new system at least half the original weight. This required analysis of the original system to determine key performance indictors (KPI's)

Strong & Lightweight Design Concept

Key to delivering a successful lightweight design was to use a smart combination of materials and the thorough use of upfront simulation to arrive at the best possible balance of weight and performance. For commercial exploitation, no tooling investment was anticipated and a short production time was essential.

Step 1 – Wing Concept Design (CAD)

For the wing section we opted for a NACA 6412 profile which is reasonably aggressive and provides good downforce and low drag (at low Reynolds numbers). The profile was inverted and scaled to suit the size of the existing wing and describe the aerodynamic surface of the wing.



We chose to 3D print the ribs in ABS and repeating these at regular intervals, this presented the best solution to define the consistent aerodynamic surface of the main wing. This provided complete geometric freedom when designing in CAD and the ribs would be bonded to a pultruded composite box section which forms the main stringer and a strong backbone for the wing.

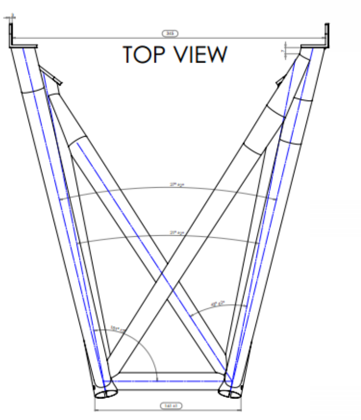
Secondary winglets are 3D printed entirely in ABS where the internal core used a lightweight honeycomb geometry (defined by the 3D printer) for its core. The secondary winglets provide extra downforce and help divert air over the front wheels and are mounted outboard enough not to restrict air into the side pods.

The flat endplates control the wingtip vortices and are water jetted from a flat section of carbon fibre comprising of 3 layers and cured in an epoxy resin. The water jetting includes the holes for aluminium rivets used to fasten the endplates and provide angle of attach adjustment on the secondary winglets.

A single ply of polyester film shrink wrapped to the structure which is stiff enough to transfer aerodynamic loads but flexible enough to wrap around the profile. The wing is complete.

Step 2 – Noseframe Concept Design (CAD)

From the BLiSS (Butted Lightweight Innovative Steel Structures) R&D project - where Simpact & WMG worked with Reynolds tubing to deliver a lightweight vehicle spaceframe (10% mass reduction) from the innovative application of butted tubing - we chose this concept for the triangular noseframe structure that connects the wing to the car. This relatively open spaceframe concept provides an efficient loadpath and marries well to the existing spaceframe chassis.

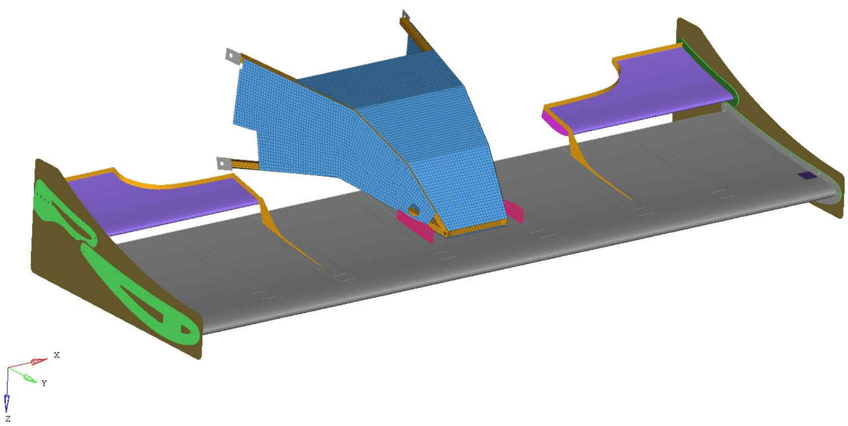


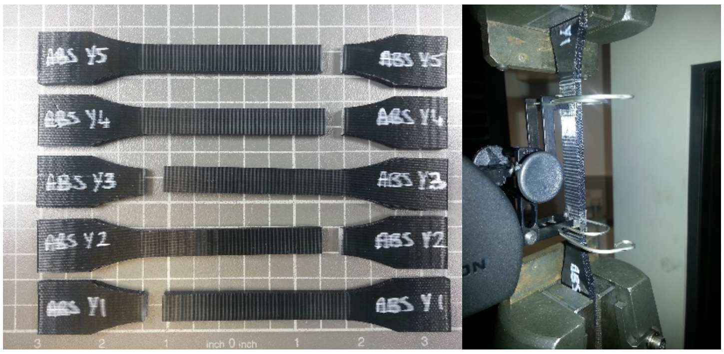
The design made use of existing (off the shelf) butted tubing that Reynolds had in stock. For example, the diagonals (in the top view above) made use of tapered rear chain stay tubes (used to support the rear wheels on bicycles) where the tube thickness is 0.8mm at the top joint and thins down to 0.4mm. Requiring no tooling investment, it is well suited for low volume manufacture. The structure is secured to the chassis using fasteners (for quick disassembly).

For the strong and stiff connection which is required between the nose structure and front wing and a component that offered the versatility to adjust wing angle of attack - this was the part selected for metal ALM.

Step 3 – Finite Element Analysis & Optimisation (CAE)

As the concept CAD design for the complete front wing assembly was in place and CAD for the original nose structure available, a finite element model of the complete front wing assembly was built. The mesh needed to be suitable for both linear and non-linear analysis and made use of a combination of finite elements depending on their suitability including beams, shells and 3D elements.



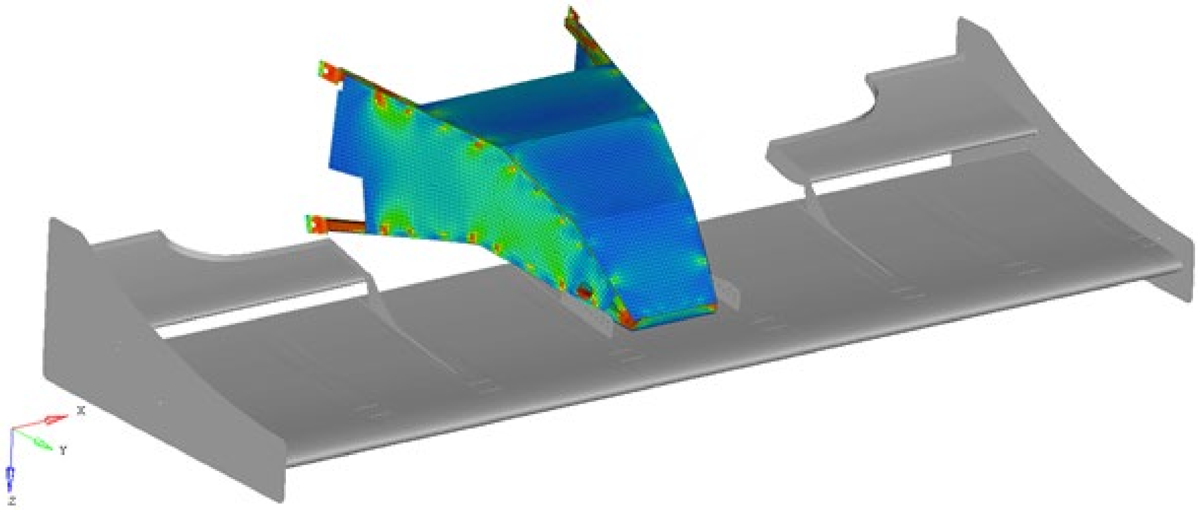


Material property data was applied from existing database and in the case were material properties were unknown samples were made and tensile testing carried out to obtain the relevant material parameters.

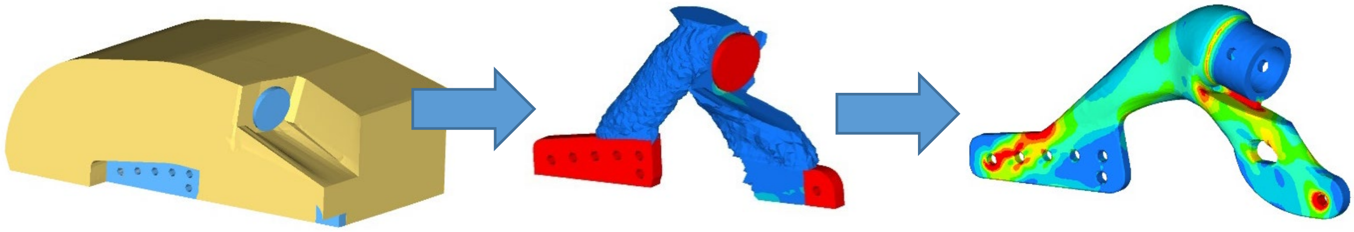
The above image shown ABS 3D printed samples tested at WMG using their tensile test machine. Material anisotropy was observed with build orientation but this was not significant.

Baseline Analysis & Shape Optimisation

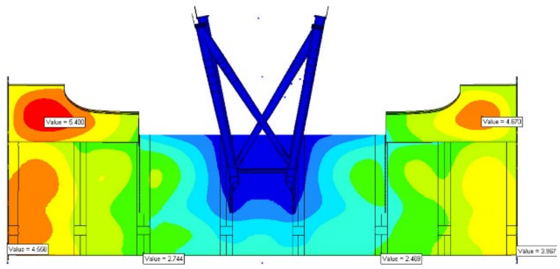
With a baseline model of the assembly developed, this enabled an understanding of the strength of the existing nosebox (which uses square box section tubing with stressed aluminium panelling) to the derived loadcases but also a calculation of the interface loads with the front wing.



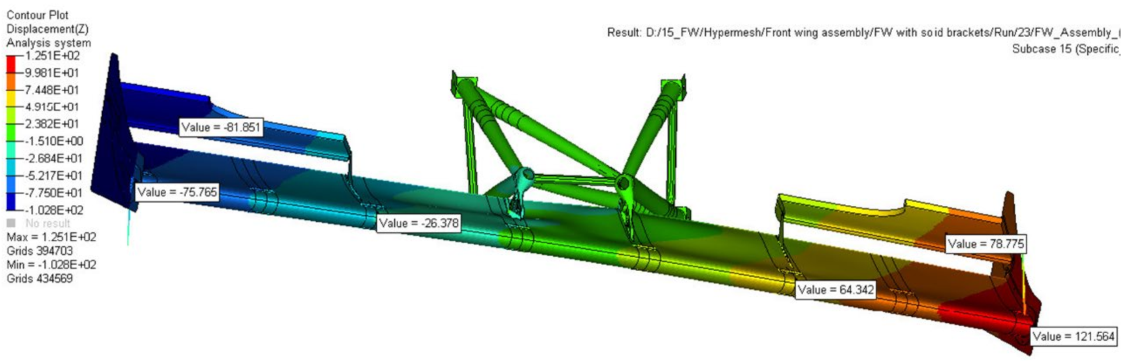
This information and a target setting exercise on the allowable displacements provided the inputs required for a topology optimisation exercise to derive the basic shape of the component of the metal ALM component. The only constraints being the design volume available and the design for the fixation/adjustment. The image below shows the evolution of the design in Optistruct.



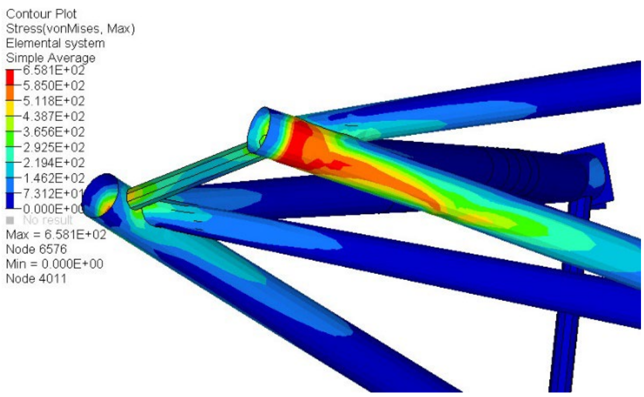
The baseline optimisation drove the v-shaped bracket shown above and the need for a high strength material. Maraging steel was chosen for the sinter material as the EOS data sheet offered very good material properties (2000MPa yield stress) and part accuracy. Although the above derived design was solid in section at this stage of the optimisation, it enabled for the detailed analysis and fine-tuning and weight reduction of the complete system and other wing component assemblies.

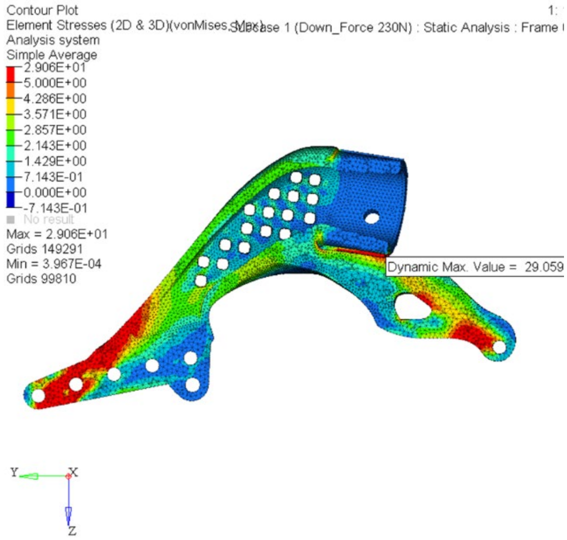


The image on the left shows a displacement contour plot from one of the in-service loadcases (uniformly distributed loading – note the slight asymmetric vertical displacement due to the asymmetric nose frame design)



By analysing the component stresses in relation to the material limiting values and considering a factor of safety, we were able to fine tune material thicknesses down to thinnest available and drive as much weight out of the system as possible.





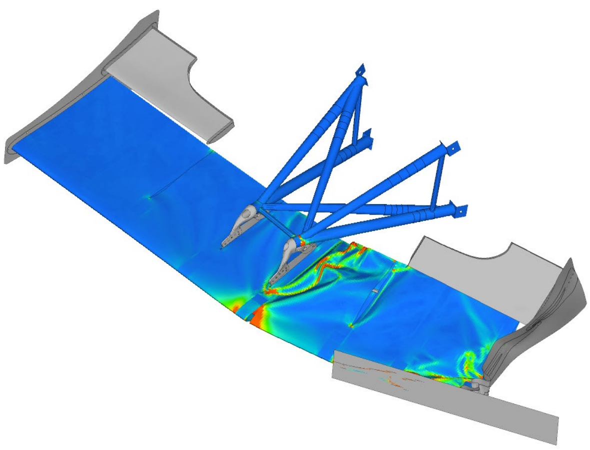
This led to a much lighter version of the metal ALM bracket which weighed just 144gms (was 210gms). A cross section of the model is shown on the left and the hollow section also allows for un-sintered support material to be removed post manufacture.

Generation of an STL file for this component means that it is now ready for manufacture.

Impact loading

To complete the analysis work, the finite element model was converted for analysis with the RADIOSS explicit time integration solver. RADIOSS is well suited to the analysis of impact loading and is also available within the Altair HyperWorks software.

This enabled analysis of the assembly under impact or crash loadcases where material plasticity is involved and deformations can be large. The nose frame structure was connected to a mass and velocity representative of the racing car (joined via a rigid body) and both full frontal rigid barrier and kerb strike scenarios analysed. The image below shows the plastic strains resulting from the latter loadcase which is more likely in hill climbing where the car spins and the front corner of the front wing hits say an Armco barrier.



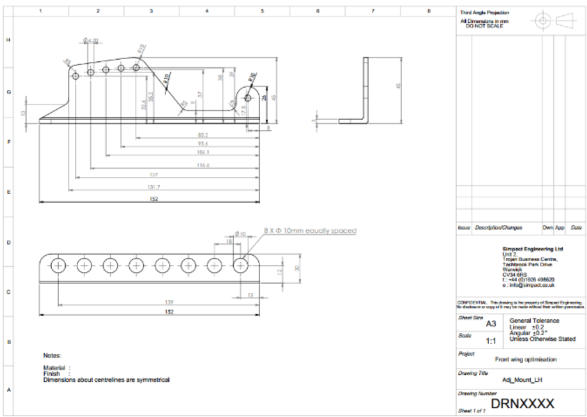
Important target for the impact loadcases was to have sacrificial failure and energy absorption in the wing rather than the supporting nose structure as this is a more economic and desirable scenario.

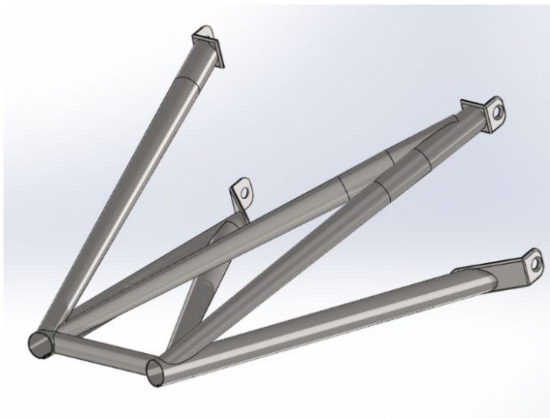
Step 4 – CAD Detailing

The CAD was updated to include the recommendations from the FE analysis and detailed for manufacture. A small hole and splines were added to the rear of the component allow for insertion into the nose structure and bonding and fastening with a single rivet. The image below is a rendering of the metal ALM bracket which when converted to an STL file, ready for sintering using the metal ALM machine.

.DXF profiles of the tubing was extracted from the resulting CAD of the nose structure in SolidWorks. This was necessary as the tubing which will be supplied by Reynolds will need to be laser cut.

For parts such as the L-brackets which connect the ALM brackets to the front wing, flat steel offered the best and most economic method these were drawn up in the traditional manner.



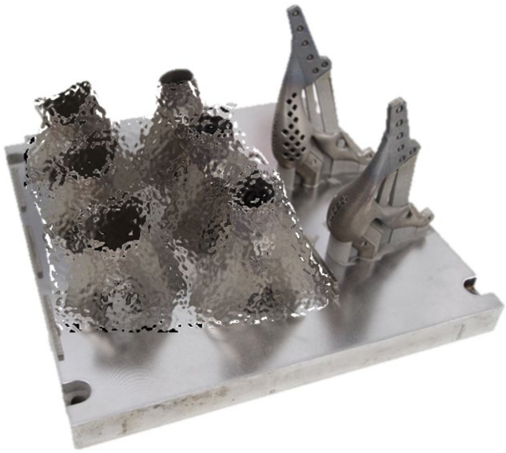


Step 5 – Manufacture & Assembly

The front nose structure was manufactured by Arch Motor Co in Huntingdon and are well known for specialising in the manufacture of automotive spaceframes. The supplied Reynolds tubing was braze welded and then powder coated.

The NACA aerofoil profiles were printed in ABS overnight on the Fortus 3D printer at WMG. These were then adhesively bonded to a composite pultrusion making up the main backbone of the wing.

The metal ALM brackets are shown to the right (with customer confidential items blurred) after SLS printing on the EOSINT M280. These are then heat treated to relieve residual stresses and a wire erosion process is used to cut the brackets from the bedplate and remove unwanted build material.



Step 6 – Conclusions & Testing

With the first prototype of the wing now built and the new noseframe in production, it was time to test the assembly at a local test track (Curborough Sprint Course in Lichfield) and the picture below shows the car accelerating out of the Fradley Hairpin.

The second set of photos show the car back at our workshop complete with Reynolds lightweight noseframe and metal ALM brackets.

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