Bloodhound: an engineering and educational adventure

At the first African Altair Technology Conference (ATCx) held at River Meadow Manor, Irene, Gauteng on 28 March 2017, Christopher Maxwell from Bloodhound SSC presented some of the technology behind the car being developed to break the land speed record – by breaching the 1 000 mph benchmark – and Altair's involvement with the project.

Late in 2018, the team behind the Bloodhound supersonic car (SSC) will attempt to set its first World Land Speed Record by travelling at over 763.035 mph or 1 227.985 km/h, a benchmark set over twenty years ago. The attempt is to take place on the Hakskeen Pan in the Northern Cape of South Africa, initially with a world record speed of 800 mph being targeted.

The ultimate goal for the team, which is being led by the past and the current world land speed record holder Richard Noble and Wing Commander Andy Green, is to break the 1 000 mph mark, or 1 600 km/h – with Andy Green in the driving seat.

The Bloodhound SSC is 13.5 m long and 4.5 m high. It produces a total of just under 1.0 MW of power (127 000 hp), weighs 7 500 kg and is designed for a top speed of 1 690 km/h, approaching Mach 1.4.

Less than half of its thrust is provided by a Eurojet EJ200, a military turbofan used by the Eurofighter Typhoon. "Air is pumped into the inlet pipe of the EJ200 at 700 km/h to start up the turbines. When running, the air flowing over the monocoque of the car is aerodynamically slowed down before reaching the intake duct so that the 9:1 thrust to weight ratio can be generated on combustion," explains Maxwell, adding that the EJ200 takes the car up to about 1 300 km/h.

From there, a hybrid rocket engine from the Norwegian aerospace and defence company, Nammo, will kick in to push the car's speed over the final hurdle. The Nammo hybrid rocket is designed to house high-test hydrogen peroxide (HTP) as the oxidiser and hydroxyl terminated poly-butadiene (HTPB) as the fuel grain.

Liquid HTP is pumped at roughly 40 litres per second through a silver-plated catalyst pack at extremely high temperature and pressure (around 70 bar). The catalyst pack causes the peroxide (H_2O_2) to decompose into steam (H_2O) and oxygen (O_2), which is released at 600 °C into the combustion chamber.

The O_2 ignites the synthetic rubber creating very hot combustion gases (3 000 °C) at high pressure. The gases are forced out through a nozzle to produce lower pressure at high velocity, which creates the rocket's thrust.

A cluster of four Nammo rockets was chosen for the final design. "Initially, the rocket engine was placed above the EJ200, but this caused unequal down force into the ground. A suggestion by a nine-year old primary school learner, however, to put the rocket engine below the jet engine, was used to resolve this problem," notes Maxwell, by way of emphasising the value of the educational aspects of the Bloodhound programme.

An auxiliary power unit – a 550 bhp Jaguar Supercharged V8 engine – is also required to pump the HTP from the fuel tanks into the hybrid rocket engine. The Jaguar engine has to sit alongside to the HTP tank, but it is vital that the heat from the engine doesn't transfer to the HTP itself, which could cause it to explode. The engine's exhaust is, therefore, covered with a ceramic coating that reduces its surface temperature by 30%.

Optimising the air brakes with HyperMesh and HyperWorks

The Bloodhound will cover the measure mile (1.6 km) record segment in 3.6 seconds. It then needs to be stopped within the confines of the 19.3 km test track. Aerodynamic drag will first slow the car down to about 1 300 km/h. Then, two ram-actuated airbrakes, one on each side of the car, will open outward from the car's body. A parachute it then deployed to provide increased drag. These are designed to slow the car to 300 km/h, so that the wheel brakes can be safely engaged.

Because of the position of the airbrakes, their actuator arms and door hinges could be no larger than 0.6 m^2 and no thicker than 50 mm. A door machined from a single piece of aluminium and a composite door structure were considered.

The material used had to exhibit a minimum first natural frequency of at least 45 Hz and had to withstand aerodynamic loading when deployed at speed, without excessive deflection or flapping. Modelling and finite element analysis (FEA) – using HyperMesh and HyperWorks from Altair Engineering – were used to accurately represent the stiffness of the entire assembly during modal analysis.

The analysis determined that a hybrid 'door' construction with an aluminium honeycomb core sandwiched between carbon fibre face sheets was the optimal solution. The resulting doors weigh only 19 kg each, compared to 70 kg for the fully aluminium versions.

The fastest wheels in history

Spin tests on Bloodhound's wheels, carried out at Rolls-Royce's test facility in Derby, saw the wheels successfully spun to 10 429 rpm. The results were satisfyingly similar to the predictions calculated using Altair's Hyperworks simulation software. The expansion of the wheel's 902.6 mm diameter by 1.6 mm was as expected, as was the 'dishing' caused by the variation in expansion rates between the wheel's aerospace grade aluminium (Al 7037) and its steel hub.

Design tweaks earlier in the process ensured that these deflections would fall well within acceptable parameters. Vibration frequencies were also "pretty damned close" to those predicted, according to Bloodhound's Lead Stress Analyst, Roland Dennison.

The goat's head

Another major piece of work recently completed was the front suspension assembly, now known as the 'goat's head'. This is an aluminium structure that supports the front wheels, suspension and steering and must be able to carry loads of up to 300 kN.

The goat's head structure has to be both light and hugely strong, and was designed using Altair's topological optimisation software, a software technique that starts with a solid block of virtual metal and removes every possible bit of material that is not absolutely necessary. The goat's head look was a result of this process, done using Altair HyperWorks' OptiStruct design-synthesis technology.

Following topology optimisation, the component was machined from a solid aluminium billet on a 5-axis machine at AMRC Sheffield. The process took, in total, 97 days of machining, which reduced the goat's head weight to just 68 kg, with 856 kg of trimmings being recycled.

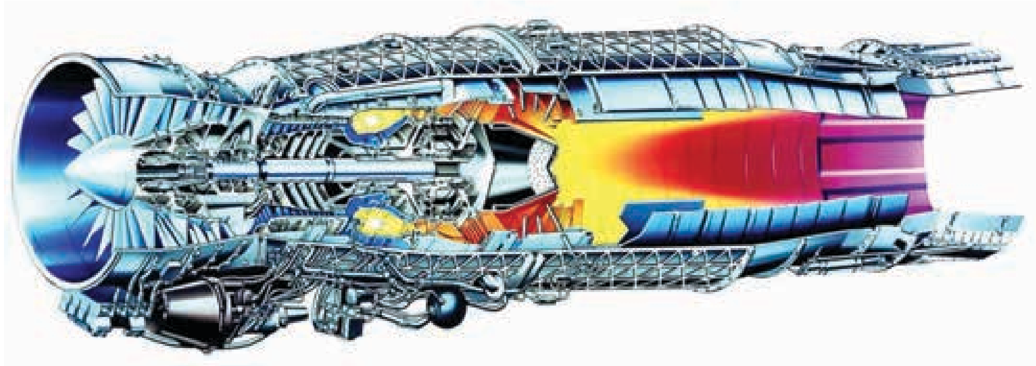
Why build a 1 690 km/h car?

Showing a picture of the late Neil Armstrong with Andy Green, Maxwell says that both of these legends are champions of the educational side of this project. "Our core aim is to create a surge in the popularity of science, mathematics, engineering and technology," he says.

"We have an education programme involving over 10 000 schools participating in designing rocket cars that are tested in school playgrounds at speeds of up to 600 km/h – and we have primary school students using CAD/CAM to build these vehicles," he says.

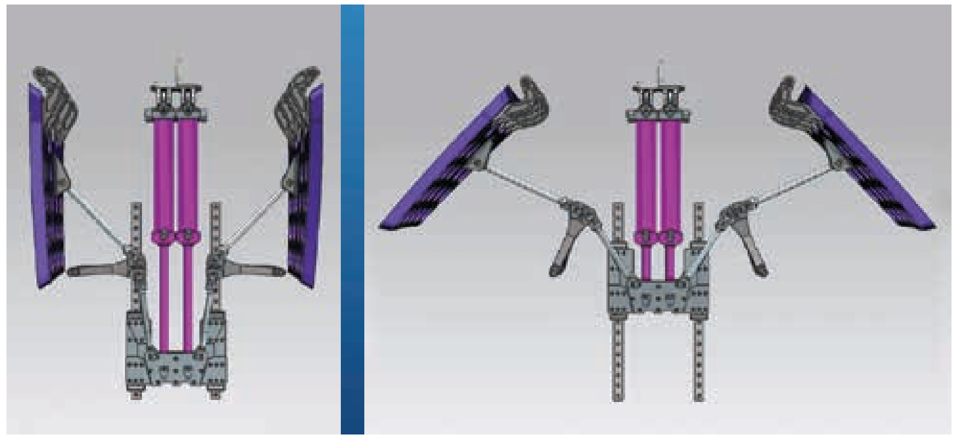
"Following the Apollo Space Programme in the 1960s, there was a massive spike in the number of physics PhDs. This was known as the Apollo effect," Maxwell points out.

"We aim to do similarly via the Bloodhound effect. We hope to inspire a new generation of people to come through the ranks, not only at university level but across the spectrum of technological careers," he concludes. ❑



About half of its thrust is provided by a Eurojet EJ200, a military turbofan used by the Eurofighter Typhoon.

The Bloodhound SSC is 13.5 m long and 4.5 m high. It produces a total of nearly 1.0 MW of power, weighs 7 500 kg and is designed for a top speed of 1 690 km/h, approaching Mach 1.4.



From about 1 300 km/h, two ram-actuated airbrakes – modelled and designed using HyperMesh and HyperWorks from Altair Engineering – will open outward from the car's body. These will slow the car to 300 km/h before the wheel brakes can be safely engaged.