Development and Testing of the BLOODHOUND SSC Hybrid Rocket

In the very early stages of the Project, BLOODHOUND SSC was intended to be purely rocket-powered. While this offered certain performance advantages, rockets are not as easy to control as jets, so it was decided to combine both powerplants to gain power and control.

The hybrid rocket for BLOODHOUND SSC will be the largest of its kind ever made in the UK. In order to accelerate the car to 1000mph it will provide an average thrust of 111 kN (25,000lbf) for 20 seconds. The peak thrust will be 122kN (27,500lbf). The development of such a large rocket is an enormous technical challenge.

A rocket is basically and engine which carries both a fuel and oxidiser (it does not require any oxygen from the air). In the early stages of the project we looked at three main types of rocket: solid, liquid and hybrid propellant.

- Solid propellant rockets are simple, reliable and offer good performance. However, once ignited they cannot easily be stopped, making them unsuitable for Land Speed Record car, which may need to slow down at any point during a run.
- Liquid propellant rockets offer high performance, although they are very complex.
- Hybrid propellant systems use a solid fuel and a liquid oxidiser. The fuel is contained within the combustion chamber and the liquid oxidiser is injected at the top of the chamber. A hybrid can be easily shut-down by turning off the supply of liquid oxidiser.

It was decided that a hybrid was the most suitable choice for BLOODHOUND SSC.

Hydroxyl-Terminated Polybutadiene (HTPB), a synthetic rubber, was selected as the primary fuel.

All liquid oxidisers are hazardous, although the hazards take different forms. The most common is liquid oxygen, a cryogenic liquid with a boiling point of -183^{o}C. It is difficult to handle and even minor contact with skin can result in serious frostbite.

Nitric acid is another efficient, high-density oxidiser. It is however toxic, corrosive and gives off choking fumes.

HTP, which we have selected as our oxidiser, is concentrated hydrogen peroxide H_20_2 (in this case 86%, the remainder being water). It is a strong oxidising agent and has a high specific gravity (a desirable property in this application). It is non-toxic and although it can cause burns, rapid washing with water can reduce the effect to a mild bleaching of the skin.

HTP was used in the UK space programme of the 1950's, 60's and 70's in rockets such as Black Knight and Black Arrow, which used liquid fuel engines burning kerosene. These programmes had an exceptional safety record.

HTP is, however, very sensitive to contamination and can be easily decomposed by many common substances. It requires great care in handling and must only be allowed to come into contact with compatible materials; even then, storage tanks, pipe work and valves must be specially cleaned and prepared.

HTP has one other advantage: it can be decomposed by a catalyst pack and therefore used as a monopropellant to provide thrust.

At the top of the hybrid combustion chamber is the catalyst pack which contains 80 silver plated nickel mesh discs; these decompose the HTP into steam and oxygen. The reaction is given as:

$$H_2O_2 \rightarrow H_2O + O_2 + HEAT$$

The decomposition generates a temperature of around 600°C – enough to spontaneously ignite the solid fuel grain. This simplifies the engine by removing the need for a separate ignition system.

BLOODHOUND SSC will carry 963kg (2100lbs) of HTP in a lightweight tank at 1.65bar (25lbs / in2). It will be supplied to the chamber by a high speed pump – in this instance, one based on the design used on the Stentor rocket engine which powered the Blue Steel cruise missile of the 1960's. The pump was upgraded for us by its original designer and is now 15% more efficient.

In Blue Steel the pump was driven by a 50,000rpm turbine powered by HTP decomposers. This was not considered suitable for BLOODHOUND, so it was decided the pump would be driven by a piston engine. The engine selected is a Cosworth CA 2010 Formula 1 motor, weighing 95kgs and producing c. 800bhp. Aside from driving the pump, it also serves as the auxiliary power unit supporting the car's electrical and hydraulic systems.

Most of the rocket development work so far has been conducted on a smaller research chamber. The 15.2cm (6 inch) diameter chamber has provide an excellent development tool. Over the course of ten firings conducted at Falcon Project's test facilities in the Mojave Desert, it has proved invaluable in the refinement of the catalyst pack, fuel grain and thermal insulation for the full size hybrid chamber.

The principle design challenge for a hybrid rocket chamber is achieving efficient mixing.

Although high specific impulse figures are often quoted for hybrids, these are frequently the theoretical values assuming 100% combustion efficiency at the optimum mixture ratio. This is rarely achieved in practice.

The target specific impulse for the BLOODHOUND SSC chamber is 200 lbs/sec/lbs. This was achieved on the second 15.2cm (6 inch) firing. Later tests have delivered over 230lbs/sec/lbs.

The work on the 15.2cm (6 inch) chamber also included a research programme to create a full CFD model to enable a more complete understanding of how the mixing, flow, heat transfer and chamber arrangement affect combustion efficiency. The combustion modelling was conducted in conjunction with the National Physical Laboratory and Fluid Gravity Ltd.

While the 6-inch test programme continued, on the other side of the of the test site a massive reinforced concrete stand for the full size test rig was constructed.

In order to withstand the huge force exerted by the 18 inch hybrid chamber, the large horizontal test stand required eight 0.91 meter (3 feet) diameter x 3.66m (12 feet) reinforced concrete pilings to be sunk. Onto these foundations a base was constructed which carried the 0.61m (2ft) thick blast wall. This was designed to carry the thrust from the chamber and also protect the HTP tank, V8 engine/HTP pump and other ancillaries.

Other infrastructure to support the tests included a water deluge system and trenches to carry high-pressure gas and electrical cable.

Three static tests of the 44.5kN (10,000lbf) thrust monopropellant chamber were conducted in July 2009.

On the 17th October 2009, the first static firing of the 45.7cm (18 inch) hybrid was successfully completed, this was a relatively low pressure firing and used nitrogen to feed the HTP to the chamber rather than the HTP pump. The test confirmed that we can achieve the required specific impulse of 200lb/sec/lb. The system performed perfectly during the 10 second firing and was in excellent condition afterwards.

With all the rocket system elements now in place, by the third quarter of 2011 we expect to have completed three further development firings using the HTP pump driven by the Cosworth V8. We will then begin a programme of safety and acceptance testing to establish that the system if ready for use in the BLOODHOUND SSC.