SABRE and Skylon – the Future of Spaceflight
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The SABRE (Synergetic Air-Breathing Rocket Engine) is a project with over 30 years of evolution behind it, and is poised to step forward dramatically from rig-based concept proving to demonstration stages that will address more operational-ready issues. There is considerable confidence growing from a string of successes that have carried the company's development team forward, incrementally and now gradually accelerating as new staff are being hired, and new funding sources are supporting an increasingly wide-ranging vision.

Mark Thomas is relatively new to the team, but well-acquainted with its history, which he related to the vision of three founder: Alan Bond (now semi-retired), and his two most long-serving consorts, Richard Varvill (Technical Director) and John Scott-Scott (a widely-respected engineer who passed away recently). He started by referring to the challenge facing space-system users, whose satellite-launch costs are an extravagant overhead. He highlighted the need for a more financially attractive and technically robust solution than current pure-rocket operations: he envisages a vehicle which will be reusable (up to 200 launches), have a 1:20,000 or better loss rate, be able to be turned around in 48hr, and have an abort rate of 1 per cent or better. The value of space operations was not the only issue driving Reaction Engines to promote their solution, as they believe that society needs a launch system with the capacity to react too to any significant events – whether naturally occurring or from more sinister activities - that disrupt space systems vital for essential humanitarian applications. The core of this vision is the SABRE engine. This operates in two rocket modes, initially in air-breathing mode and subsequently in conventional rocket mode, a combination which offers enhanced performance over an all-rocket solution. In both modes thrust is generated using the rocket combustion chamber and nozzles. By using air-breathing engine technology up to an altitude and speed of 25,000m (82,000ft) and Mach 5 (3,000kts) the oxidiser payload is reduced considerably: making a 320 tonne vehicle able to offer orbital height/payload combinations that require a traditional 850 tonne rocket.

The SABRE concept presents a higher specific impulse solution over the speed range involved in an orbital launch than any equivalent single or hybrid solution. At the lower speeds it acts like a conventional jet engine, in terms of compressor, combustion and turbine, with a traditional multi-shock conical intake to slow incoming air to sub-sonic speeds, and has a 'pre-cooler' or heat exchanger between the intake and the compressor face. This is necessary as the decelerated air heats to some 1000^{O}C. The company's innovation has devised and demonstrated a design that will cool air almost to a liquid at -150^{O}C in 1/100th of a second. It was shown to have evolved over some 30 years, most notably incorporating a high-pressure (200 bar) closed-circuit Helium system which manages heat transfer in both the air-breathing and rocket modes. He quoted the equivalent thrust of the definitive SABRE to be an 80 tonne (circa 176,000lb (783kN)) jet engine and a 200 tonne (400,000lb (1,960kN)) rocket. The pre-cooler has required a considerable period of innovative design effort and led to the company investing in a bespoke manufacturing cell it now uses to make units that have been demonstrated on over 500 test-rig trials, and have shown the system's ability to cope with frost accumulation. In the definitive design the pre-cooler will weigh 1.5 tonnes, and handle 400MW total heat transfer. This design will incorporate 1500km of nano-scale Nickel Alloy tubes. The possibility that this high-energy density technology can be transferred into other disciplines is not being overlooked by the company.

An impressive moment in the presentation was a brief film of the company's test rig at its Culham base. It uses a Viper engine and it has been on this facility that the company has conducted proof of concept trials. It uses liquid Nitrogen rather than Hydrogen for cooling to cryogenic temperatures (minimising hazard and cost issues) and an internal camera showed how the cooled airflow flowed radially through the circular pre-cooler prior to it being ingested by the engine compressor.

Skylon is the vehicle that has had a great bearing on the scale of the proposed engine, and at this stage it is a concept rather than a definitive design. With proof of concept milestones on SABRE development being passed rapidly, much of Reaction Engine's expansion in the last year or so has centred on integration with other companies with appropriate materials, production and integration skills and has shifted towards total system design. It is clearly also aligned to opening the possibility of more funding opportunities that will support the definition of an actual single-stage to orbit (SSTO) space vehicle.

It is envisaged as a 325 tonne unmanned orbital payload delivery vehicle. The mass breakdown starts with a 53 tonne dry mass (empty aircraft), 251 tonnes of fuels, 6 tonnes of consumables and a 15 tonne payload. The aircraft has a conventional aircraft configuration, and the engines are located on the wing-tips, thus close to the centre of gravity. Each nacelle is a 'banana' shape, and this is a function of matching angle-of attack and thrust alignment throughout the Mach 25 speed range of this landmark vehicle. The Question and Answers session, opened specifically to younger audience members for brief period, revealed some of these finer points, and made clear their enthralment with what is a rare and remarkable vision of what technology might deliver in their lifetimes. The take-off speed was cited as 170m/sec (330kts), and a 5km runway is required: not specifically for a long take-off run, but to accommodate abort scenarios that draw on existing aircraft safety-related practices. A trajectory drawing showed that the aircraft would climb relatively steeply and the time to orbit on a typical mission was cited as 16 minutes.

There was indication of a potential structural design concept with thermal expansion and conductivity, structural rigidly and lightness amongst the integration aspects facing designers. He postulated a 'truss' based construction and was clear that this is one area where innovative design must be conducted most immediately. In terms of partnerships the presenter stressed the ways that the systemic attributes that will need to be balanced and the need to engage the vehicle and airframe as a product. Proof of concept demonstrations are targeted for enactment in 2023/2025.

This was an enthralling presentation that had attracted 190 attendees, and received a particularly warm reception. We have a student to thank too for revealing his own SSTO design agonies on the space simulation program Kerbel: the wry reaction of a CEO whose job it is to manage such work in real-life included acknowledgement that the 'game' is not unfamiliar to some of those within the cloisters of his own team.

Lecture notes by Mike Hirst

The diagrams below (from Reaction Engines website – well worth a visit) show the SABRE engine helium cycle cooling system in air-breathing and rocket operating modes (upper and lower parts respectively), and a cutaway of Skylon.