September 2013

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U.K. advances air-breathing rocket technology

Space launches that use single-stage-to-orbit, air-breathing rocket motor technology came a step closer to reality in July: The U.K. government announced that it is investing £60 million ($90 million) over the next two years in Reaction Engines' synergetic air-breathing rocket engine, or SABRE, program.

The U.K. Space Agency explains, "SABRE has the potential to create 21,000 high-value engineering and manufacturing jobs; maximize the U.K.'s access to a conservatively estimated £13.8-billion launcher market over the next 30 years; and provide economic benefits from spillover technology markets."

Reaction Engines, a U.K. company, has designed SABRE to extract the oxygen it needs for low atmosphere flight from the air itself, paving the way for a new generation of spacecraft. Lighter and reusable, these vehicles would be able to take off and launch from conventional airport runways. They could also deliver payloads weighing up to 15 tonnes into LEO, for about one-fiftieth of what it would cost if traditional ELVs were used, says the space agency, which has invested the money in SABRE on behalf of the government.

Managing hot air

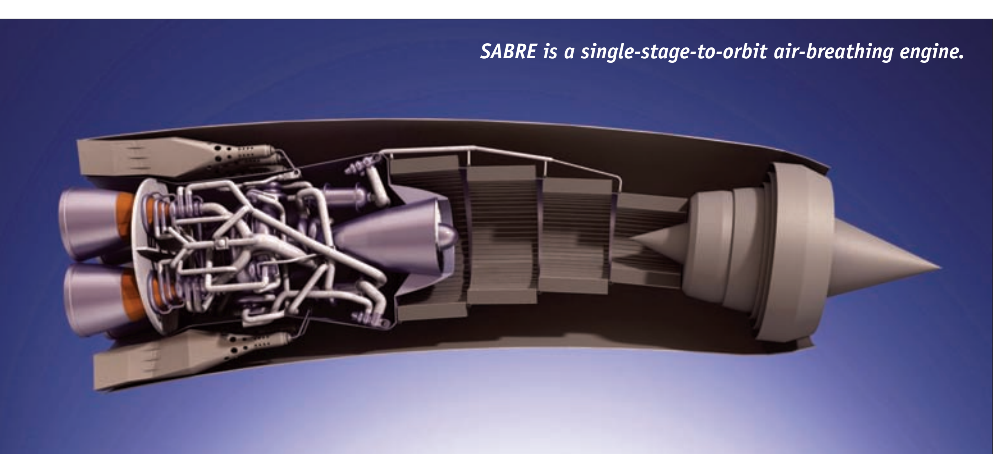
In November 2012 the engine concept passed a series of vital tests that validated the performance of the heat exchanger module. That is the key enabling technology needed for managing hot air as it enters the engine at high speeds.

One of the main challenges to developing a rocket engine with an air-breathing capability is that the air must be compressed to around 140 atmospheres before being injected into the combustion chambers, raising its temperature so high that it would melt any known material. So instead, SABRE first uses a precooler heat exchanger to cool the air until it is almost a liquid. Thus a relatively conventional turbo compressor using jet engine technology can be employed to then compress the air to the required pressure.

Initial work on developing fairly lightweight, efficient, and enduring precooler modules to cool the incoming airstream continuously from over 1,000 C to -150 C in less than 0.01 sec was completed in July 2012. The European Space Agency independently validated the resultant technology on behalf of the U.K. agency. According to ESA, the precooler test objectives "have all been successfully met, and ESA is satisfied that the tests demonstrate the technology required for the SABRE engine development."

"The modules have proved to be extremely robust," says Alan Bond, a founding director of Reaction Engines and inventor of the SABRE engine. "In terms of stability, we've shown the concept is mechanically, thermally, and aerodynamically stable, so we're in good shape.

"What do we have to do to get it to operation? We think we're already there. We've finished with the 're-search' part of the research and development process, and the next step is development of a proper precooler."



SABRE is a single-stage-to-orbit air-breathing engine.

Next steps

The work on developing a demonstrator has now started, with the U.K. government's investment staged over two years of the work—£35 million ($53 million) in 2014-2015, and £25 million ($38 million) in 2015-2016.

"Phase three of the program is to come up with a validated engine design, undertaking all the rig work on the components, and to develop manufacturing drawings and the facilities designed ready for the production phase," says Bond. "We hope to have this all completed by the end of 2017. Beyond that, if the funding is in place, we would expect during 2018 to see the first engines begin their test phase."

Financial hurdles

Before a SABRE-powered spacecraft takes to the skies, however, Reaction Engines has three other major challenges to overcome.

The first is financial: Although the £60 million investment from the U.K. government will provide an important boost to the company's next phase of development, the total amount required for this phase is likely to be around £250 million ($381 million).

The company is now talking to aerospace companies to set up an industrial partnership to manage the program's technology development and commercial production phases. At the moment, 95% of the manufacturing of components and structures takes place in-house, where the company produces turbines, blades, compressors, and nozzles for other projects.

The SABRE engine features innovative designs for contrarotating turbines, combustion chambers, rocket nozzles, and air intakes. However, much of their production will be outsourced, leaving the company to take the lead in engine/airframe integration and heat-exchanger modules. In developing the key components, Reaction Engines has worked with a number of European suppliers and is confident that the appropriate partners will be found.

Skylon

The second key challenge is to pick a strategic partner to develop the airframe that will house SABRE. In addition to the engine research, Reaction Engines has been working on developing the spacecraft that it calls Skylon, an 84-m-long unpiloted vehicle.

"We are designing a real engine for [it] and can't afford to get the overall concept wrong, so we've had to specify the vehicle in quite a lot of detail," says Bond. He estimates that airframe research has taken up about 15% of the company's activities.

"We've been working on the structure and aeroshell for quite a long time and built engineering models of the structure and tested it. We undertook a lot of analysis on the reentry phase in the early days of the project, because we weren't going to pursue a concept that was simply not going to work. The German Aerospace Center [DLR] carried out a lot of modeling on this vehicle, and the thermal environment is more benign than we originally thought.


Reaction Engines has been working on the Skylon spacecraft to house the SABRE engine.

"We expect to see the vehicle coming together in parallel and the preproduction prototype vehicles flying about 2020."

Under the current operational concept, Skylon would carry fuel only for launching the vehicle into space. It would use its aerodynamic lifting design and onboard flight control system to manage the descent and landing phase. However, Bond suggests that if an operator decided to have an extra margin available for the return trip and was prepared to carry extra propellant rather than satellites, there would be no reason why the engine could not be lit again.

In the meantime, there has been an independent study on the market for non-aerospace spinoff applications from the technologies researched for SABRE. The study has identified a number of potential new revenue streams in areas such as thermal and power engineering. "We are starting to examine what the realities for those markets are, and whether we should set up parallel operations," says Bond.

Certification

The third challenge is to ensure there is a regulatory system in place to certify the new technology. In March, according to Reaction Engines, the U.K. Dept. of Transport began a one-year study into the requirements for certification of the SABRE engine, and the company has already delivered a position document as part of the research work.

It is as yet unclear whether the engine and airframe will be certified under U.K. or European regulations, via the European Aviation Safety Agency in Cologne, Germany. However, the company has set itself a demanding schedule, with parallel work streams under way to conclude certification, airframe development, and the production of a small-scale version of the final engine within a tight timeframe.

Current emphasis

Current development work involves continuing to improve the lightweight heat exchanger technology and manufacturing capability, to lower the pre-

Inside SABRE

SABRE's design would eliminate the need for the on-board oxidant required by conventional rocket launchers, and for the massive first stages that are jettisoned once the oxidant they contain has been used up. In the initial air-breathing mode the rocket engine sucks in atmospheric air (as in a typical jet engine) as a source of oxygen to burn with its liquid hydrogen fuel in the rocket combustion chamber.

According to Reaction Engines, "The air-breathing mode can be used until the engine has reached over five times the speed of sound and an altitude of 25 km, which is 20% of the speed and 20% of the altitude needed to reach orbit. The remaining 80% can be achieved using the SABRE engines in rocket mode. For space access, the thrust during air-breathing ascent is variable but around 200 tonnes per engine. During rocket ascent this rises to 300 tonnes but is then throttled down towards the end of the ascent to limit the longitudinal acceleration to 3.0 g."

As the air density falls with altitude, the engine eventually switches to a pure rocket, propelling its vehicle to orbital velocity (around Mach 25).

In both modes the thrust is generated using the rocket combustion chamber and nozzles. This is made possible through a synthesis of elements from rocket and gas turbine technology.

cooler temperature regime and evolve the design further. A prototype SABRE is expected by 2017, with flight tests for the engine around 2020.

But Bond is confident that the schedule can be met. "It took SpaceX just four-and-a-half years to go from a standing start to having an expendable launch vehicle up in the air, a level of performance not seen since the Cold War years. So it shows it can be done."

Longer term concepts

SABRE and Skylon are not the only European next-generation launch concepts under consideration. Research is under way on two projects—the DLR's SpaceLiner and Aerospace Innovation's ALPHA aircraft—as part of a European Commission strategic research effort. Called FAST20XX (Future High-Altitude High-Speed Transport 20XX), this EC program has been assessing the potential benefits of producing a single vehicle for both hypersonic passenger transport and space launch applications. They are at a very early stage compared with Skylon and SABRE, however, and involve 17 European research agencies investigating a wide number of enabling technologies. These include active cooling on the aircraft nose and wing leading edges, and optimized airflow around the aircraft itself.

But now that it has validated the most important technology enabler to realizing the SABRE concept—and secured the backing of the U.K. government for the industrialization phase of the program—Reaction Engines is confident its innovative design will revolutionize space transportation services for many decades to come.

Philip Butterworth-Hayes
Brighton, U.K.
phayes@mistral.co.uk

Correspondence

Erratum J.R. Wilson is the author of **UAV Roundup 2013** (July-August, page 26) and the supplement. His name was omitted due to a printing error.

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In **Time to roll up our sleeves** (June, page 3), Elaine Camhi has accurately described the problem of debris in space. We must find a way to control this problem just as we must find ways to control other pollution problems in and below the atmosphere.

As with most pollution, space debris can be explained by the tragedy of the commons: Farmers put more livestock on the commons until overgrazing ruins the commons. Like the commons, the solution is proper feedback.

Space is a resource. As we are learning, it is not limitless. When we use some of space, we are essentially taking what was available to all and claiming it for ourselves. Until we are forced to pay for taking this resource, we will take more and more.

We could agree to let an international body collect a small tax from any use of space as long as a satellite or vehicle is in space. The proceeds of the tax can then be used to remove debris. The tax could be insignificant for those using space properly, even for 25 years after the useful life ends, but if the tax continues for longer times, it would become significant.

Jim Martin
Huntington Beach, California

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In the June 8 entry for "50 Years Ago, June 1963," in **Out of the Past** (page 46) the references to Titan II force structure and capabilities are in error. We believe an accurate description is: "The Titan II held a target range of 5,500 mi [9,200 km]. The 390th Strategic Missile Wing (Davis-Monthan AFB), the 381st Strategic Missile Wing (McConnell AFB) and the 308th Strategic Missile Wing (Little Rock AFB) were each charged to maintain and be prepared to launch Titan II ICBMs on lawful order. Each of the three wings bore 18 missiles, totalling 54." (From http://www.titan-ii.com/)

Note: There were only two Titan II ICBM squadrons in the 390th Strategic Missile Wing at Davis-Monthan AFB, not six. Each squadron had nine missiles for a total of 18 missiles at Davis Monthan AFB, not 357.

Arthur Barondes
Col. USAF (Ret.)

All letters addressed to the editor are considered to be submitted for possible publication, unless it is expressly stated otherwise. All letters are subject to editing for length and to author response. Letters should be sent to: Correspondence, Aerospace America, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344, or by e-mail to: elainec@aiaa.org.

Events Calendar

SEPT. 10-12
AIAA SPACE 2013 Conference and Exposition. San Diego, California.
Contact: 703/264-7500

SEPT. 17-21
International Conference on Jets, Wakes, and Separated Flows. Nagoya, Japan.
Contact: Ephraim Gutmark, 513.556.1227; www.icjwsf2013.org

SEPT. 23-27
Sixty-fourth International Astronautical Conference. Beijing, China.
Contact: http://www.iac2013.org

SEPT. 24-25
Atmospheric and Ground Effects on Aircraft Noise. Sevilla, Spain.
Contact: Nico van Oosten, nico@anotecc.com; www.win.tue.nl/ceas-ascza