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Will Skylon fly?

A British company continues to press toward the goal of a single-stage-to-orbit space plane, despite questions from some in the hypersonics community about the design's feasibility. Keith Button explores the project's challenges with its technical director and outside experts.

It's been a dream for decades: Build a space plane with airbreathing engines so you can avoid the weight and drag of carrying oxygen with you for combustion. While you're at it, reuse your vehicle, like an airplane, so you can save the time and money of building a new one for every trip.

That's the goal of the U.K.-funded Skylon project led by Reaction Engines Limited, or REL, of Abingdon in the U.K., where engineers aim to build a reusable 325-ton space plane that would deliver a 15-ton payload to a 300-kilometer orbit.

Skylon would be propelled by two liquid hydrogen-fueled Synergistic Air-Breathing Rocket Engines, or SABRE for short, that would operate in two modes. The flight would start in the airbreathing mode, in which the engines would gather oxygen for combustion from the atmosphere. This mode would accelerate Skylon to 4,220 mph, at which point the engines would shift to a rocket mode in which they would draw hydrogen and oxygen from tanks to reach orbit at 19,000 mph.

The technical challenges facing Skylon are enormous. The engines must be protected from severe heating but the components providing that protection can't be so heavy that Skylon can't reach orbit. Some in the global hypersonics research community doubt that the concept is feasible, even as they admire the company for trying and see promise in some aspects of the concept.

The SABRE engine "has a lot of advantages over any other concept that I know of. But the going to space [with a] single stage — that's still science fiction, in my view," says Michael Smart, head of supersonic combustion ramjet research at the University of Queensland's Centre for Hypersonics in Brisbane, Australia. He considers himself a Skylon skeptic, and he is not alone.

The question is whether Reaction Engines, which plans to begin engine component testing this year in preparation for ground testing in 2019, can prove the doubters wrong. That would amount to achieving something the U.S. spent hundreds of millions of dollars trying but failed to do in the 1980s under the Pentagon-NASA X-30 National Aero-Space Plane program and in the 1990s under NASA's X-33 Venture Star program.

Reaction Engines is well aware of this history, and its executives do not downplay the challenges.

"Single stage to orbit is the most technically difficult way of getting into space, but it has the most promise, in terms of getting the cost down. If you can make the vehicle reusable, then you have an airplane on your hands, instead of a multistage rocket that needs refurbishing and rebuilding every time you fly it," says Richard Varvill, the company's technical director and chief designer.

Controlling weight

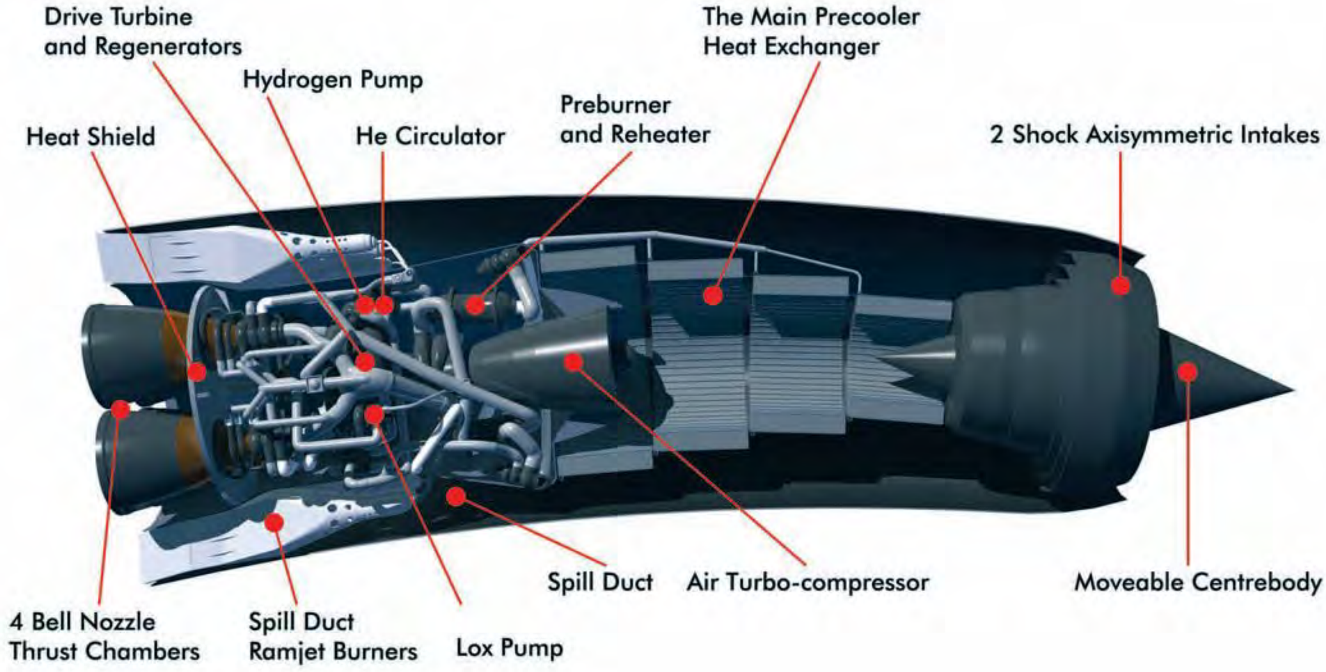
Hypersonics experts like to say that a particular component or technology must earn its way into a design, and often the weight of the technology is the deciding factor. That's how it is for Skylon, too.

"Can you engineer [each] component to the weight required? That's really where the challenge lies. And we're still doing a lot of work inside the company to try and convince ourselves of that," Varvill says.

For SABRE, the problem springs largely from the fact that it will require a helium-cooled chamber, called a precooler, to chill the incoming air, which will be in a superheated state after being slowed to subsonic speeds for combustion. If the precooler can be made light enough, the payoff could be enormous. With the air now flowing sub-

Reaction Engines

Engineers and designers behind U.K.'s Skylon are attempting to quell skeptics by building a reusable, single-stage space plane with an air-breathing engine that would reduce the amount of propellant carried onboard.



Skylon's two Synergistic Airbreathing Rocket Engines, or SABRE, will be crucial to determining the space plane's success. The hydrogen-powered SABRE is designed to cool and convert incoming air, reducing the vehicle's need to carry oxidizer.

Reaction Engines

sonically and at temperatures that won't melt the engine, everything beyond the precooler can be more or less conventional. Blades would compress air for combustion, similar to the process in a turbojet, and the combustion chamber and nozzles would be like those of a traditional rocket. While others in the hypersonics community are toiling to perfect exotic, bladeless air-breathing supersonic combustion ramjet engines, Reaction Engines will have sidestepped that challenge.

"It's a well-known fact that we're not fans of scramjets," Varvill says.

The precooler will be a complex device, however. Thousands of 1-millimeter-wide, helium-circulating tubes will line its walls. The helium will be cooled by Skylon's liquid hydrogen fuel.

An advantage, Varvill says, is that the SABRE engine can provide thrust over a wide velocity range, up to Mach 5.5 in fact, before switching to rocket mode.

"It's very hard to get a scramjet to operate over a range of speeds," Varvill says. That's because it must be finely tuned to maintain combustion with the extreme forces created by massive amounts of air flowing through at supersonic speeds, and with buffeting from supersonic shock waves in that flow.

A scramjet "would really like to fly at just one speed, and then you optimize the engine geometry for the one operating condition. Obviously for a launch vehicle, it has to be accelerating the whole time. That requires a lot of variable geometry inside the engine, which makes it heavy," he says.

Scramjet engines tend to be massive compared to the aircraft they propel — the engines can make up most of the airframe, running from the nose to the tail and taking up much of the diameter of the fuselage — because of the massive amounts of air they must ingest.

Need for speed

To reach low Earth orbit, Skylon must reach Mach 25. NASA earned a Guinness World Record in 2004 for flying an unmanned, scramjet-powered aircraft — the X-43A — at Mach 9.6. The question facing Skylon engineers, and one that other hypersonics researchers are keenly interested in, is how to get all the way to orbit with a meaningfully sized payload.

Among the prominent scientists in the hypersonics research community is Glenn Liston, chief of the high speed experimentation branch of the Air Force Research Laboratory at Arnold Air Force Base in Tennessee. Liston oversees research and testing of hypersonic engines to be used in missiles and, potentially, spaceplanes.

"One of the top challenges that we face is that if we're going to take something into that high-speed range, then those pieces that make high speed possible, we're going to drag them through the low-speed range; we're going to take them all the way up to space," Liston says. "They have to buy their way on. That's a challenge; they need to have enough performance to do that."

Part of deciding what earns its

way on board can be determined by the weight of the propellant compared to the overall vehicle weight. Two proposed single-stage-to-orbit vehicles from the past provide good examples of the issue, says David Van Wie, chief technologist at the Applied Physics Laboratory at Johns Hopkins University, which tests and develops scramjet engines.

The Lockheed Martin X-33 never flew, but its launch mass would have been 92 percent propellant, with only 8 percent remaining for the structure of the vehicle, control systems, engines and payload. NASA canceled the program in 2001 because of the weight and structural problems. In a 1999 test, the X-33's hydrogen tank failed when the outer skin and core of the tank wall peeled away from the inner skin.

NASP, also known as the Rockwell X-30, never flew, either, but it would have had about 70 percent of its takeoff weight devoted to propellants. Engineers ran into additional weight problems from the design elements required for carrying people aboard, plus the weight of the air-breathing engines, and the inlets and exhaust nozzles required to allow them to cover low and high speeds. NASP was canceled in 1993.

Nevertheless, many researchers continue to like the idea of operating an air-breathing engine at high Mach numbers, because such an engine could have three times the specific impulse — a measure of fuel efficiency — of a rocket engine at speeds above Mach 5, Van Wie says. That's because they don't have to carry their own oxygen. At lower speeds, without the extreme conditions created by hypersonic flight, an air-breathing engine might have 10 times the specific impulse of the rocket engine. The higher the specific impulse of an engine, the less propellant it requires and the more weight on a space plane that can be devoted to the structure and payload. But air-breathing engines also tend to be heavier than rocket engines.

About 80 percent of Skylon's takeoff weight would be propellant, Varvill says.

Lockheed Martin's X-33 was one of the failed attempts to build a single-stage-to-orbit space plane. NASA canceled it in 2001 in part because of its heavy weight, 92 percent of which was propellant.

Different approach

For now, Reaction Engines is focusing on the experimental engine. Later, the company will address the long list of design challenges from the extreme heat and buffeting conditions at Mach 25 and on re-entry into the atmosphere.

"No one has ever seen an engine like this, where the air compressor is actually driven by a helium loop. That's the new bit that people want to see demonstrated effectively," Varvill says.

By using subsonic air, and using a precooler to bring the air temperature down, the rest of the engine doesn't see the wide range of conditions that a ramjet/scramjet experiences from supersonic and hypersonic — above Mach 5 — airflows, Varvill says. The upper limit for the speed of the SABRE engine is dictated by the precooler, and limits on the range of temperatures that the metal in the heat exchanger can withstand, Varvill says.

From Mach 5.5 to Mach 25, the speed required for orbit, the SABRE engine would be in rocket mode, burning oxygen and hydrogen carried on board. As with the turbojet portion of the SABRE engine, the rocket engine mode will use technology that is typical of other modern rocket engines.

The full-sized experimental engine to be tested by 2019 will be a stripped-down version of the SABRE, built to prove the operation of the helium loop and the basic function of the engine — that it can compress air to the correct levels for liquid hydrogen combustion. The engine probably won't have an intake channel or a nozzle system, Varvill says.

At the same time, the company plans to test a smaller-scale version of the SABRE engine's precooler under high temperature conditions. In 2012, the company showed that the engine's precooling system worked at room temperatures down to cryogenic temperatures, but it didn't have funding available to test it with heated air, like the temperatures the engine would encounter at supersonic speeds, Varvill says. The air inlet on the SABRE engine would capture air moving by the vehicle at speeds up to Mach 5 and slow it down to subsonic speeds before combustion, making it very hot. Skylon now has plans to test the precooler by 2019 at potential test chamber sites that can create the Mach 5 temperature conditions and show that the precooler can cool the hot air to the desired outlet temperature.

The company's latest design, the SABRE 4 engine, is a more thermodynamically sophisticated engine that will require less liquid hydrogen than the original SABRE engine.

After the ground demonstration engine has been built and tested, sometime around 2020, another engine would be installed in a single-engine flight test vehicle. The engine and airframe would be tested under high-speed and temperature conditions.

The Skylon engineers will have to develop an outer skin for the airframe that can withstand high temperatures and remain elastic during the rigors of high-speed flight, for example, as well as develop safe fueling procedures and tanks for the liquid hydrogen, Varvill says.

The first flight test vehicle, with its single engine, would look more like a missile than a space plane, Varvill says. It would be built to test the initial stage of a flight to space — taking off from the ground and accelerating to about Mach 5 with air-breathing engines — and then the engine would shut off and the aircraft would glide back to the ground. Next would be a flight vehicle with a rocket engine to explore the ascent after Mach 5, when the air-breathing engine's inlet is closed and the air-breathing function is turned off as the engine switches to rocket mode.

Another challenge is that Skylon's engineers will have to find ways to lengthen the lifetimes of certain components, Varvill says. Skylon is looking for 200 flights out of the vehicle, for example, but a high-performance rocket combustion chamber like the one in the space shuttle main engines will begin to develop cracks after about 20 firings. With certain seals, bearings, turbopumps and compressors in the precooler of the SABRE engine, unlike with turbojet engines, oil can't be used because it will freeze. That means the bearings have to function with little lubrication, which shortens their life, he says.

Tough audience

Some question the feasibility of Reaction Engines' approach. The SABRE engine could be a significant breakthrough for air-breathing engines, but maybe for a point-to-point aircraft instead of a space plane, says Smart, the scramjet scientist at the University of Queensland.

Van Wie, the scramjet scientist at Johns Hopkins, says that even with the benefits that airbreathing engines can bring to a design, the technical problems yet to be solved means that it may be awhile before someone manages to build the first single-stage-to-orbit vehicle.

"People have talked about this going back several decades. It's kind of viewed as the Holy Grail that would provide flexible operations. But nobody yet has come up with a real detailed approach on how to achieve that," Van Wie says. "I know the Skylon crowd, they have their belief in a unique solution to do that, but it's still pretty far off into the future."

The solution will probably come from thinking smaller, says Liston, the Air Force Research Laboratory scientist.

"I think [single-stage-to-orbit] is possible and practical, but it probably won't look like the drawings we had from the mid-'60s, where you've got a 1 million to 2 million pound vehicle that takes off, flies to space and comes back after delivering a 10,000-pound payload," Liston says.

Instead, it may make more sense to optimize a space plane for carrying small payloads — with a plane the size of a B-1 bomber or even as small as an F-15 fighter. Large payloads would be left to the expendable launch vehicles like the Delta 4 and the Atlas 5.

"We don't have millions of trains around, but we have millions of trucks to move things off the trains," Liston says.

Keith Button
buttonkeith@gmail.com