



The Next Space Shuttle: Hybrid Engines Make Runway-To-Orbit Missions A Reality

A new type of engine could usher in an era of affordable spaceplanes

By NICOLE DYER SEPTEMBER 10, 2013

A disembodied jet engine, attached to a hulking air vent, sits in an outdoor test facility at the Culham Science Center in Oxfordshire, England. When the engine screams to life, columns of steam billow from the vent, giving the impression of an industrial smokestack. Engineer Alan Bond sees something more futuristic. "We're looking at a revolution in transportation," he says. For Bond, the engine represents the beginning of the world's first fully reusable spaceship, a new kind of craft that promises to do what no space-faring vehicle ever has: offer reliable, affordable, and regular round-trip access to low Earth orbit.

Bond and the engineers at Reaction Engines, the aerospace company he founded with two colleagues in 1989, refer to the future craft as the Skylon. The vehicle would have a fuselage reminiscent of the Concorde and take off like a conventional airliner, accelerate to Mach 5.2, and blast out of the atmosphere like a rocket. On the return trip, Skylon would touch down on the same runway it launched from.

Bond's Synergistic Air-Breathing Rocket Engine (Sabre)—part chemical rocket, part jet engine—will make Skylon possible. Sabre has the unique ability to use oxygen in the air rather than from external liquid-oxygen tanks like those on the space shuttle. Strapped to a spacecraft, engines of this breed would eliminate the need for expendable boosters, which make launching people and things into space slow and expensive. "The Skylon could be ready to head back to space within two days of landing," says Mark Hemsell, future-programs director at Reaction Engines. By comparison, the space shuttle, which required an external fuel tank and two rocket boosters, took about two months to turn around (due to damage incurred during launch and splashdown) and cost \$100 million. Citing Skylon's simplicity, Hemsell estimates a mission could cost as little as \$10 million. That price would even undercut the \$50 million sum that private spaceflight company SpaceX plans to charge to launch cargo on its two-stage *Falcon 9* rocket.

The engine produces incredible heat as it pushes toward space, and heat is a problem. Hot air is difficult to compress, and poor compression in the combustion chamber yields a weak and inefficient engine. Sabre must be able to cool that air quickly, before it gets to the turbocompressor. In November, Reaction Engines hit a critical milestone when it successfully tested the prototype's ability to inhale blistering-hot air and then flash-chill it without generating

mission-ending frost. David Willetts, British minister for universities and science, called the achievement "remarkable."

The Skylon concept has also impressed the European Space Agency (ESA), which audited Reaction Engines' designs last year and found no technical impediments to building the craft. The bigger challenge may be securing funding. While ESA and the British government have invested a combined \$92 million in the project, Bond and his crew plan to turn to public and private investors for the remaining \$3.6 billion necessary to complete the engine, which they say could be ready for flight tests in the next four years. Building the craft itself would require a much heavier investment: \$14 billion.

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The quest for a single-stage-to-orbit spaceship, or SSTO, has bedeviled aerospace engineers for decades. Bond's own exploration of the topic began in the early 1980s, when he was a young engineer working with Rolls-Royce as part of a team tasked with developing a reusable spacecraft for British Aerospace. That's when he came up with the idea of a hybrid engine. But the team struggled to figure out how to cool the engine at supersonic speeds without adding crippling amounts of weight. "By the time the plane hits Mach 2 or so, the air becomes very hot and extremely difficult to compress," Bond says. Rolls-Royce and the British government, doubtful that an easy and economical solution existed, canceled the program's funding.

NASA and Lockheed Martin, meanwhile, had their own plans for a fully reusable spacecraft, the VentureStar, intended as an affordable replacement for the partially reusable space shuttle. The VentureStar demonstrator, called X-33 (which graced the cover of this magazine in 1996), was a squat, triangular rocket that would take off vertically and glide back to Earth just as the shuttle did. Eliminating the expendable rockets needed to boost the shuttle into space could theoretically reduce the cost of launches from \$10,000 per pound to \$1,000 per pound. But by 2001, after sinking more than \$1 billion into the project, the agency pulled the plug, citing repeated technical setbacks and ballooning costs. "We backed off because we felt it was better to focus our efforts on other, less costly ways to get payloads to orbit," says Dan Dumbacher, NASA's deputy associate administrator for exploration systems development, who spent two years working on the X-33.

With the shuttle now retired, and companies such as SpaceX under contract to resupply the International Space Station (ISS), NASA has doubled down on expendable boosters as a means of sending humans and probes well beyond Earth's orbit. NASA's new platform for deep-space exploration, the Space Launch System, will be the most powerful rocket ever built. The agency's focus on space exploration, and the need for big rockets to achieve it, means NASA no longer needs to build its own platforms just to get cargo into orbit. "From a pure technical perspective, we'd all love to go do SSTO," Dumbacher says. "But we're focused on making sure we get humans farther into space, and that's an expensive proposition."

Expendable rockets make sense for missions beyond low-Earth orbit. They can haul more cargo and more fuel than single-stage craft. Rockets also offer reliability—on average, only one out of 20 launches fail, in part because they suffer no wear and tear from repeated use. Finally, rockets come with fewer R&D costs, as much of the technology has existed since the 1960s.

But for routine missions to the ISS, or to park a small observational satellite in orbit, affordability becomes a critical consideration. SpaceX CEO Elon Musk told an audience at the National Press Club in 2011 that private spaceflights would need to follow a model closer to that of airlines. "If planes were not reusable, very few people would fly," he said. SpaceX plans to make rocket stages reusable, but there are drawbacks to that, too: While it is possible to recover rocket stages,

designing bits and pieces to survive reentry in good working order adds a level of complexity and cost.

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Hempsell says Skylon could potentially make 100 flights annually—which, if true, could in its first year recoup the money spent in R&D and construction, leaving only expenses like fuel, maintenance, and overhead. And Bond's engine technology, aside from keeping a launch vehicle intact from start to finish, offers another advantage: supersonic aviation. "It could enable an aircraft to fly anywhere in the world in under four hours," says Bond.

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When air strikes an engine at five times the speed of sound, it can heat up to nearly 2,000 degrees Fahrenheit. Bleeding off that heat instantly, before the air reaches the turbocompressor and then the thrust chamber, was the most onerous technical challenge for Reaction Engines engineers. Bond's solution is a heat exchanger that works by running cold liquid helium through an array of tubes with paper-thin metal walls. As the scorching-hot air moves through the exchanger, the chilled tubing absorbs the energy, cooling the air to minus 238 degrees Fahrenheit in a fraction of a second. Bond says his exchanger could handle about 400 megawatts of heat (equivalent to a medium-size natural-gas plant). "If it were in a power station, it would probably be a 200-ton heat exchanger," he says. "The one we've built is about 1.4 tons."

For rocket scientists, nothing matters more than weight. "Each pound you put into orbit requires about 10 pounds or so of fuel to get it there," says NASA's Dumbacher. "The challenge with the SSTO has always been to get the craft as light as possible [and generate] as much thrust as possible." Bond estimates that Skylon would weigh about 358 tons at takeoff and hold enough hydrogen fuel to carry itself and about 16.5 tons of payload—about the same capacity as most operational rockets—into orbit.

If and when the engine passes flight tests, one of Reaction Engines' plans is to license the technology to a potential partner in the aerospace industry. Bond hopes the recent success of the heat exchanger will inspire interest. After 30 years of research, it has certainly inspired him. "It represents a fundamental breakthrough in propulsion technology," he says. "This is the proudest moment of my life."

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