SpaceShipOne: Riding a White Knight to space

Burt Rutan's new vehicle, which uses classic elements of earlier designs, may bring low-cost access to space a step closer

Burt Rutan, designer of the round-the-world Voyager airplane, is said to have a good chance of claiming the X-Prize—a $10-million award for the first team to fly a three-person vehicle to 328,000 ft (100 km), recover it, and fly it again two weeks later. He will attempt this feat with the new Tier One vehicle, built by his Scaled Composites company and sponsored by an unidentified investor.

Winning the prize, though, is only the first step. Rutan has said that, if his company claims the prize, he intends to fly the vehicle into space every Tuesday for five months—20 flights, a week apart, on schedule. He plans, in other words, to demonstrate "aircraft-like operations" in a spacecraft—meaning only routine maintenance and inspections would be required between flights. This could be the key to less expensive access to space for military users, scientific researchers, and private industry, possibly opening the door to space tourism as well.

From X-15 to Tier One

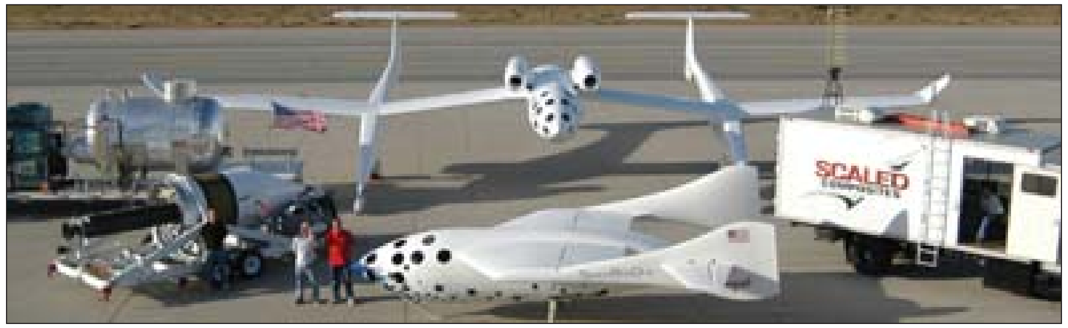
Rutan's Tier One is a two-stage, horizontal takeoff and landing vehicle comprising a rocket-powered upper stage launched from a subsonic, jet-powered mothership. This approach is analogous to that of the North American X-15, funded by the National Advisory Committee for Aeronautics in its 1950s heyday and tested in the 1960s. The third X-15, flown by NASA test pilot Joe Walker, made two 100-km-plus flights about a month apart in the summer of 1963.

The fundamental difference between the X-15 and the Tier One is the trajectory. Designed for high-speed research, the X-15 ascended and descended like an airplane, reentering the atmosphere at a moderate angle of attack and transitioning quickly to airplane-like flight. With such a reentry, proper attitude is critical—"a few degrees of sideslip and you die," says Rutan. Only the third X-15, which had a much better stability-augmentation system than

Rutan's approach to launch is much like the one used for the X-15 in the 1950s.

by **Bill Sweetman**

The elements of SpaceShipOne include the subsonic mothership, called White Knight (top) and the rocket-powered upper stage, dubbed Tier One.



the other two aircraft, was intentionally flown above 250,000 ft.

Rutan's goal of low cost ruled out such a system. Instead, the designer has aimed for "carefree" reentry, with a near-vertical trajectory and a vehicle so stable aerodynamically that it does not need autostabilization. His first X-Prize design was a rocket that would descend like a shuttlecock, with a ring of stabilizing "feathers." Suspended by a parachute during its descent, it would be recovered in midair by a helicopter. The technique had been used to retrieve film capsules from reconnaissance satellites until the mid-1970s. This approach, however, involved an extra vehicle—the recovery helicopter—and the risks and costs associated with a large parachute.

SpaceShipOne, the rocket element of Tier One, is designed to reenter like a stable shuttlecock, then glide and land like an airplane. The wings, with an ultralow aspect ratio of 1.7, span 16.4 ft. Their size is based on the requirement to provide enough lift to rotate the vehicle into its ascent attitude after horizontal launch, and to permit conventional gliding approaches and landings. At the top of the climb, the rear part of the wing and the tailbooms—still known collectively as the "feather"—hinge upwards. As the spacecraft starts to reenter the atmosphere, the feather stabilizes it in a flat attitude with the slab-like wings at right angles to the airflow.

This creates so much drag in relation to the vehicle's weight (without fuel) that peak heating is moderate. SpaceShipOne is constructed from conventional graphite-epoxy composite materials, with some limited use of high-temperature epoxies. Hotter sections are protected by a simple "trowel-on" ablative thermal protection layer. In the worst case envisaged by the test team, the fuselage may be damaged but the occupants will be unharmed.

Space suits and high-altitude full-pressure suits are high-maintenance items—Scaled Composites used them when it was testing the Proteus high-altitude research aircraft. But the three-person SpaceShipOne cabin is sealed, pressurized, and double-walled, and the occupants enjoy a short-sleeve environment. Normal entry is via a small plug-type door, and the nosecone can be jettisoned for emergency egress.

A hybrid rocket was chosen for the spacecraft, and it has undergone broad test firing.

Hybrid rocket design

Rutan has chosen a hybrid rocket for the spacecraft, burning solid fuel—a synthetic rubber—with the aid of nitrous oxide (N_2O), a liquid oxidizer. Hybrid rockets have been studied and tested for many years, and a success in this program would be a major boost for the concept. SpaceShipOne uses a pressurized oxidizer tank, eliminating the need for fuel pumps. The fuel is pumped into the tank at 300 psi and 0 F and reaches a pressure of 700 psi at room temperature. The oxidizer flows through the propellant-lined motor case, where combustion takes place.

Hybrid rockets are less complex than liquid-fuel engines, requiring no fuel pumps. They are safer and offer higher performance than solids, and they can be throttled or shut off, unlike solid motors. Nitrous oxide can be safely stored at room temperature: Rutan's trailer-mounted fuel-handling system is routinely stored, full of N_2O, in the company's hangar at Mojave, Calif.

Two companies—SpaceDev of San Diego and Miami-based Environmental Aeroscience—were competing to develop the rocket casing and nozzle, located behind the fuel tank. In September, SpaceDev was named the winner .

Manual flight controls

SpaceShipOne's cockpit is a sealed environment, obviating the need for space suits.

SpaceShipOne has three flight control systems, all of them under direct manual control, with no intervening computers. A conventional cable-and-rod system is used at low speeds. At supersonic speeds, the pilot uses electric trimmers to adjust the vehicle's trajectory, just as Chuck Yeager used the electric trim on the XS-1 to make the first supersonic flight in 1947. Cold gas thrusters linked to the stick and pedals are used when the vehicle is above the atmosphere. The landing gear and feather are actuated by a 6,000-psi compressed-air system.

The flight profile involves some unusual attitudes, spurring development of an innovative navigation and display system. The two-module system comprises a GPS/inertial navigation and attitude reference unit and a pilot's display with a single large LCD screen. The display places the aircraft at the center of a globe, with latitude and longitude lines. The globe's equator forms the horizon. In a near-vertical climb, for instance, the pilot can keep the aircraft on course by reference to the longitude lines and hold the correct climb angle with the help of the latitude lines. Scaled Composites pilot Mike Melvill describes the system as "incredibly intuitive."

White Knight carrier aircraft

The 82-ft-span carrier aircraft, named White Knight, is designed specifically for the launch mission. The twin-boom layout, with deep booms and a cranked wing, raises the center section high enough to clear the space vehicle without requiring a long and heavy landing gear. The lance-like boom extensions that give White Knight its name carry fixed nosewheels fitted with spats—little tear-drop fairings. The spacecraft is rolled into place under the airplane on a simple three-point dolly, cranked up by hand, and mated to a stout two-point pylon. Two General Electric J85 engines, rated at 3,500 lb of thrust with afterburning, are installed above the aircraft's center section.

White Knight's cabin, low-speed flight controls, and avionics are all the same as those of the spacecraft. The cabin pressurization system is also similar. These are part of Rutan's ingenious approach to the program—White Knight is not only the carrier aircraft, but also the trainer and systems test-bed for SpaceShipOne. With oversized airbrakes deployed, it has the same lift-to-drag ratio and glide performance that the spaceship has on landing.

Supporting the air vehicles is a simulator with a powerful home-grown visual system—"Keep arms and legs inside the spaceship at all times," warned a notice on the simulator at the roll-out. The system is driven by an array of PCs. Other support equipment includes the fuel trailer and a mobile rocket test stand.

Takeoff and flight

The entire system weighs around 19,000 lb at takeoff. White Knight is designed to lift SpaceShipOne to 50,000 ft, where the rocket can operate in a near-vacuum condition. The spacecraft—weighing some 8,000 lb fully fueled—is released in level flight and pulls up into a shallow climb before the motor fires. The pilot immediately pulls up into a 65° climb and the spacecraft accelerates quickly, reaching a peak climb rate of 170,000 ft/min, a maximum acceleration of 3-4 *g*s, and a maximum Mach number of 3.5. The trajectory gradually steepens, becoming almost vertical. The indicated airspeed does not exceed 240 kt, because the craft is above most of the atmosphere before it reaches its maximum velocity.

The greatest speed and acceleration are achieved immediately before burnout, when the vehicle is lightest. After burnout, the spacecraft continues to coast upward under its own momentum, with its crew enjoying some 3.5 min of weightlessness as it follows a ballistic arc peaking above 328,000 ft. The pilot commands the feather into the recovery position as the descent begins, and the passengers will experience 4-5 *g*s as the craft enters the atmosphere. At

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Although the current vehicle is meant for a pilot and two passengers, it is completely scalable.

85,000 ft, the feather retracts and SpaceShipOne becomes a glider under manual control. Although its wings are short, it is relatively light without fuel. Immediately before touchdown, the main landing gear wheels and nose skid are extended by springs and gravity.

Maintenance and testing

The vehicle is designed to require minimal maintenance after each flight. The rocket tube will be removed and replaced by a new unit, full of fuel. The rocket nozzle, which is protected from exhaust heat by an ablative coating, will have to be removed, reconditioned, and possibly replaced. The thermal protective material will be restored. The X-Prize rule—that no more than 10% of the vehicle's mass can be replaced between flights—enforces an efficient design.

The project has not involved wind tunnel testing, raising some eyebrows around the industry. "It's a challenge to go to 330,000 ft in any aircraft," comments one pilot. "Until it's flown, we don't know which motions are divergent and which are convergent." Computational fluid dynamics techniques have been used to model the aerodynamic and thermal effects around the spacecraft, but the use of manual controls exclusively outside the atmosphere is still a first. Some observers note, too, that composite materials can lose strength rapidly at elevated temperatures.

However, the advantage Rutan has over some of the all-rocket X-Prize contenders is that he can explore his flight envelope in careful increments, measured in rocket motor burn time, and can make necessary changes if the project runs into trouble.

Potential applications

Tier One is not an operational vehicle but a proof-of-concept design. The Tier One combination, says Rutan, is scalable. The designer has suggested that a 10-passenger suborbital spacecraft would be more likely to be a profitable space tour-bus than SpaceShipOne, which carries only two passengers in addition to the pilot. At the other end of the scale, Rutan has suggested a massive aircraft with eight 747-type engines, capable of carrying a 600,000-lb spacecraft—two orders of magnitude larger than SpaceShipOne.

The Aerospace Corporation, in a 2002 report, identified direct uses for suborbital vehicles in markets as diverse as military reconnaissance, fast package delivery, and tourism. In May 2002, pollster Zogby International released the results of a space tourism poll funded by NASA. Zogby interviewed 450 millionaires, and 19% indicated they would be willing to pay $100,000 per seat for a 15-min ride to suborbital space. This represents an encouraging market for suborbital space tourism, considering that in 2000 there were 7 million people with a net worth over $1 million.

In June, the USAF and DARPA issued a draft solicitation for a project known as Falcon (Force Application and Launch from CONUS). Although the long-term goal of Falcon is a hypersonic cruise vehicle, it also calls for a near-term small launch vehicle, a system with two missions. One is to launch a small satellite (220-2,200 lb) into a Sun-synchronous, 280-mi. orbit at a 79° inclination. The other is to launch the common aero vehicle, a hypersonic gliding missile, over intercontinental distances. Tier One technology—particularly its propulsion and reentry technology—could form the basis for such a vehicle, with the addition of a small, inexpensive, expendable upper stage.

According to Brig. Gen. Simon Worden, the USAF's director of space transformation, the Air Force is increasingly interested in "tactical space." In Iraq, he noted, "it would have been nice to have capabilities tailored to the crisis"—for example, small, limited-life "microsats" in orbits that brought them low over the theatre. "We're excited about microsats, and we're beginning to put serious money into them," Worden says. Rutan's design, which uses room-temperature propellants and conventional runways, could form the basis of a candidate launcher.

The new Scaled Composites craft, therefore, is much more than just a record-breaker. It is a technology demonstrator—a privately funded X-plane—and its descendants could meet a wide range of military and commercial requirements.