Soon a winged rocket will drop from a B-52 bomber flying at 40,000 feet, climb to a low-Earth orbit, and release a small satellite. A pair of private companies has developed this unique orbital booster to cut the time and cost currently required to put small payloads into space.

By STUART F. BROWN

A Pegasus air-launched space booster climbs upward from the B-52 bomber that launched it.

WINGING IT INTO SPACE

If you want to climb a tree—but you aren't tall enough to grasp the lowest limb—then find someone who will boost you up on his shoulders. That's the reasoning behind a new-style satellite launching system designed to put small payloads into low-Earth orbit at a reasonable price.

The idea will be tested in August when a 36-year-old Boeing B-52 bomber clutching a slender spacecraft under its wing begins a long takeoff roll at the NASA Dryden Flight Research Facility in the California desert. At first glance onlookers might think they are witnessing a revival of the famous North American Aviation X-15 rocket planes that made high-speed flights into near-Earth space in the 1960s.

The mistake would be understandable. This particular B-52 carried many X-15 missions to their launch points high in the sky. Similar in weight and overall dimensions to the celebrated X-15, the craft that will be slung under the bomber also has a wing, a tail, and a black color scheme. But that is where the resemblance to the rocket plane ends. The bomber's cargo is an unmanned satellite booster named Pegasus, after the winged horse of Greek mythology.

The Pegasus designers, Orbital Sciences Corp. of Fairfax, Va., and Hercules Aerospace Co. of Wilmington, Del., say that by launching their craft from an airplane flying at 40,000 feet—where it is beyond the clutches of 75 percent of Earth's drag-inducing atmosphere—they have reduced by about one-half the size of booster rocket needed to place a given payload in orbit. The efficiency of the craft's ascent is further increased by a Burt Rutan-designed delta-shaped wing that adds substantial aerodynamic lift to the raw thrust generated by the first-stage rocket engine.

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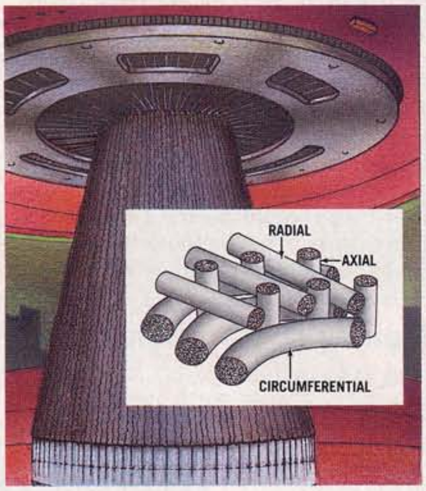


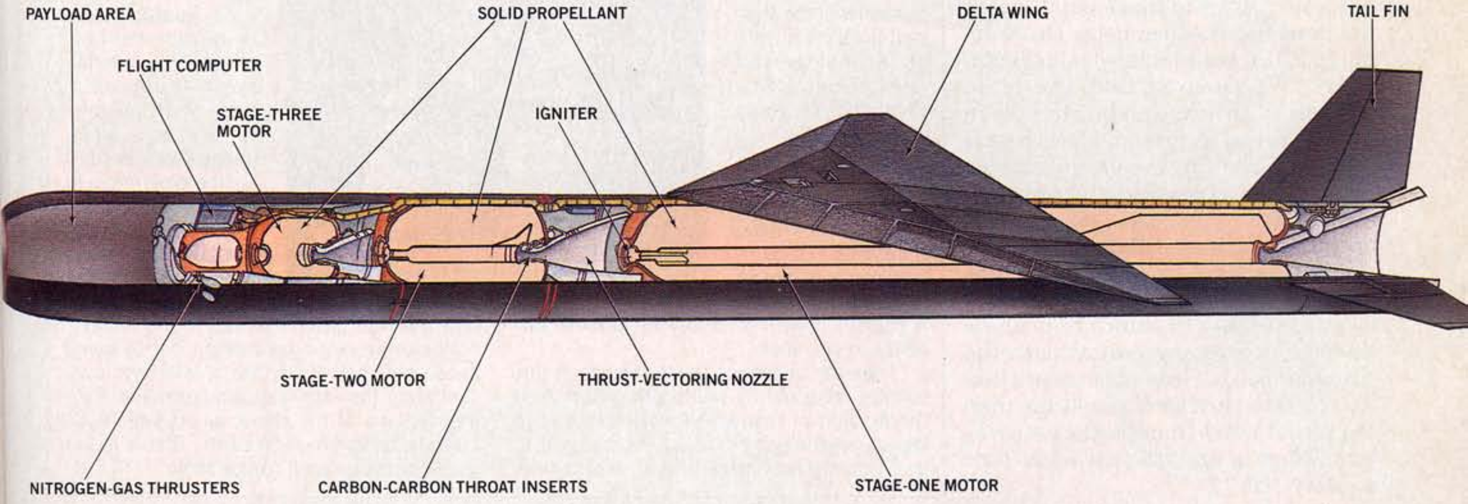
ILLUSTRATIONS BY BRIAN REGAL

At the Hercules Aerospace Co. plant in Clearfield, Utah (top left), a stage-one Pegasus motor case is produced by a large filament-winding machine that dispenses resin-coated carbon-fiber thread onto a turning form, or mandrel. The thread-dispensing pallet, tended by a technician, traverses back and forth like the action of a fishing reel to produce a crisscross pattern that gives the case great strength. Thousands of rotations are required to complete the winding process.

A completed set of first-, second-, and third-stage Pegasus motor cases (middle left) is fitted with the separation joints that connect them.

The carbon-carbon throat inserts used in the Pegasus rocket motors are made from carbon fibers (bottom left) that are put through a "three-dimensional-weaving" process on a dauntingly complex machine adapted from the apparel industry. The woven sleeve's structure is similar to a wool sock—but much thicker. Resin is then forced into the sleeve and the part is baked in an oven at high temperature and pressure. This cycle is repeated several times, eventually yielding a dense carbonized material that has good structural strength at high temperatures. Most of the applications for carbon-carbon are in space, however, because the material burns in the presence of oxygen. Ballistic missile nose tips are one use for the coal-black composite.

The rocket's ascent through the atmosphere is aided by the delta-shaped wing (drawing below) attached to its first stage; flight control is provided by three movable tail fins. After the spent first stage drops away, the craft continues ascending to orbital altitude with the rocket thrust of its second and third stages. Flight control for these stages is provided by movable thrust-vector-control exhaust nozzles and nitrogen-gas thrusters. The solid-fuel rockets are started by an igniter located at the nose end of each motor. The rocket nozzles have throat inserts of carbon-carbon material to withstand the ultra-high exhaust temperatures. Maximum payload is one-half ton.



Hustled from preliminary design to its first launch in only 2½ years, the winged rocket will be the first of a new generation of privately developed satellite launchers to loft payloads into space. At first the government will be the main customer for the small-payload launch service, but scientific and commercial customers are expected to sign up once the system proves itself.

Visiting the Pegasus project managers at Orbital Sciences, one is surprised by the dearth of talk about new technology. Adjectives like "proven" and "mature" are the buzzwords in this group.

"Although Pegasus is a new concept and a new approach to putting a payload into space, we intentionally chose components available to us off the shelf," says Scott Webster, one of the small company's founders. "We didn't have to go out and develop entirely new motor, structure, or guidance technologies. We married existing state-of-the-art components into a new system."

Commenting on OSC's seemingly short development period for Pegasus, Webster reflects, "It's not that we're doing it so unusually fast, it's just that the rest of the aerospace industry, conditioned by government requirements, does it comparatively slowly. They're conservative, and they're not spending their own money."

Cutting costs while ensuring the rocket's reliability are the program's guiding principles. There's a good reason for this: The first Pegasus customer is the Defense Advanced Research Projects Agency, which will pay a fixed \$6-million fee for launch services. If the costs exceed that figure, OSC must pick up the tab. DARPA has contracted for as many as six Pegasus launches, and it's hoped that other government agencies will follow suit.

Orbital Sciences became interested in building an air-launched rocket while pondering ways to make small satellite launches cheaper, notes Dr. Antonio L. Elias, the company's chief engineer: "We realized that the main obstacle to putting small satellites in space was cost. A ground-based rocket capable of carrying even a modest payload is quite expensive, and then you have to add in the enormous costs of the launching base with its large crew."

Using an airplane as a launch base greatly reduces these costs and provides the ability to launch from above the oceans into any orbital path the customer needs. Ground bases are limited to launch trajectories that take the rocket away from population centers, where a malfunction could pose a safety risk.

The rocket-with-a-wing idea had its genesis in a problem inherent in horizontal launching. "We ran some simulations and we realized that we would waste a lot of thrust trying to point the rocket upward for the climb to orbit after it separates from the aircraft," says Elias. "The wing generates sufficient lift to get the rocket on the right trajectory for ascent, so the thrust we are putting in is well used; it's more efficient."

A unique aspect of the Pegasus program is that the rocket is the first high-performance flying vehicle to be developed without testing scale models in wind tunnels to simulate how it would perform in hypersonic flight. Instead, the winged rocket's shape has been refined at NASA Ames Research Center by Cray supercomputers using advanced computational fluid dynamics (CFD) software—numerical codes that calculate how the air will flow past Pegasus's airframe.

Researchers at OSC and Nielsen Engineering and Research in Mountain View, Calif., used NASA's CFD facilities to assess the craft's aerodynamic performance solely on the basis of this powerful numerical method of prediction. In exchange, OSC will give NASA data from the Pegasus flights with which to enrich its CFD data base. "Pegasus will be the first time where we have a model, through CFD, of what is going to happen. Then when we fly, we will calibrate the model. CFD is a great tool, but so far it hasn't proved itself. This could be the first time it proves its worth, and that's why NASA is so interested," observes Elias.

I visited the sprawling factory in Clearfield, Utah, outside of Salt Lake City, where Hercules Aerospace fabricates Pegasus rocket engines from shiny black carbon (graphite) fiber that's been soaked in resin. The first-stage mandrel around which the synthetic fiber is wound (see photo) is referred to by workers as the "Chinese puzzle." Close examination reveals the sausage-shaped cylinder of stainless steel to be made up of a patchwork of intricately fitted pieces that are painstakingly unbolted from each other and extracted from the finished case after it has been heat-cured.

Across the broad parched valley, I got a look inside Hercules' Bacchus West facility, a highly automated complex where only about a half-dozen people in several large buildings mix and cast solid rocket propellant into the carbon-fiber engine cases. Why such a small workforce? Because this plant was built with big—albeit accidental—explosions in mind. The windowless walls are thick concrete, while the roofs are of lightweight wooden construction, a design that channels a blast upward rather than outward, where it would do more damage.

The plant's designers clearly figured that the fewer people there are around, the fewer get blown up if something goes wrong. Here and there in the upper stories of these buildings are brightly painted "breakthrough barriers" of plastic foam that you jump through if you have reason to believe that all hell is breaking loose. The barriers connect to huge round lengths of

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Making space affordable

"One of my personal goals is to demythologize space, to make space operations commonplace, and that means reducing costs," says Dr. Antonio L. Elias, the former assistant professor of aeronautics and astronautics at the Massachusetts Institute of Technology who heads Orbital Sciences Corp.'s Pegasus design team.

"For example, I can see a network of little twenty-pound microsatellites to detect distress calls from people in remote locations worldwide. A Pegasus could launch several of these satellites in one shot.

"I see the demise of space science in this country produced by the length of time and the amount of money it takes nowadays to launch anything into space. People used to be concerned that space-science experiments took longer than a graduate student's thesis time span. Now even deans of engineering wonder if they should risk their careers on a project that may not produce any useful results in their lifetime. We've headed into an awful spiral where there's no motivation or incentive to do any space science.

"I would like to bring back the couple-of-million-dollar twenty-four-months-from-cradle-to-grave space-science experiment: from designing the experiment to getting and publishing the data in the journals in two years.

"The next logical step would be to attack the high cost of medium-sized rockets, not by using exotic technology, but by being unconventional. Maybe the answer is in concentrating the expensive guidance and electronics parts of the rocket on reusable pods that can be returned to Earth. This is easier said than done, but it can be done."—*S. F. B.*

Winging it into space

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ductwork that deposit the evacuee on top of a pile of soft sand at ground level.

Robotic devices perform as many tasks as possible, including mixing the explosive propellant in gigantic stainless-steel bowls borrowed from the baking industry. "Automation prevents people from being exposed to the hazardous materials that are part of the rocket-manufacturing process," says plant manager Bob Folsom. The gloppy mix is poured into rocket motor cases that are set into deep cylindrical pits in the floor where heating elements slowly cure the propellant to its hard-rubber-like finished consistency.

Lightsats

The rationale for a launcher like Pegasus stems from the space industry's growing interest in using small, relatively inexpensive satellites—called "lightsats"—to perform various tasks in space. Last fall potential builders and users of small satellites and their launchers held a conference at Utah State University to swap ideas about likely missions for these craft.

The U.S. military would like to be able to launch on short notice small surveillance, communications, or targeting satellites that would be exclusively available to specific commanders operating on the ground. Those officers must now often do without the services of large military satellites that are busy handling other tasks.

The Air Force-NASA X-30 National Aerospace Plane (NASP) program may become another Pegasus customer, says Dr. Robert E. Lindberg, OSC's director of advanced programs. "Because our rocket can be programmed to climb at a shallow angle, it can reach a speed of Mach eight at a relatively low altitude, where aerodynamic heating is still very pronounced. This makes it useful for testing the performance of NASP airframe and engine-intake models during suborbital flights."

Finally, it is expected that small commercial communications, remote sensing, and materials-processing payloads will someday be launched into orbit by Pegasus rockets.

Early in the U.S. space program, winged space planes powered by rockets such as the X-15 were developed in parallel with ballistic missile-type boosters. After the Mercury, Gemini, and Apollo spacecraft were orbited with wingless missiles, the space shuttle was devised, which though lofted by rocket thrust, flies home on wings. Now the Pegasus prepares to wing its way into orbit. And the future X-30 aerospace plane will both ascend into space and descend upon wings. In this way, it looks like the U.S. space effort is slowly turning full circle. PS