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LOW-COST RIDES TO SPACE

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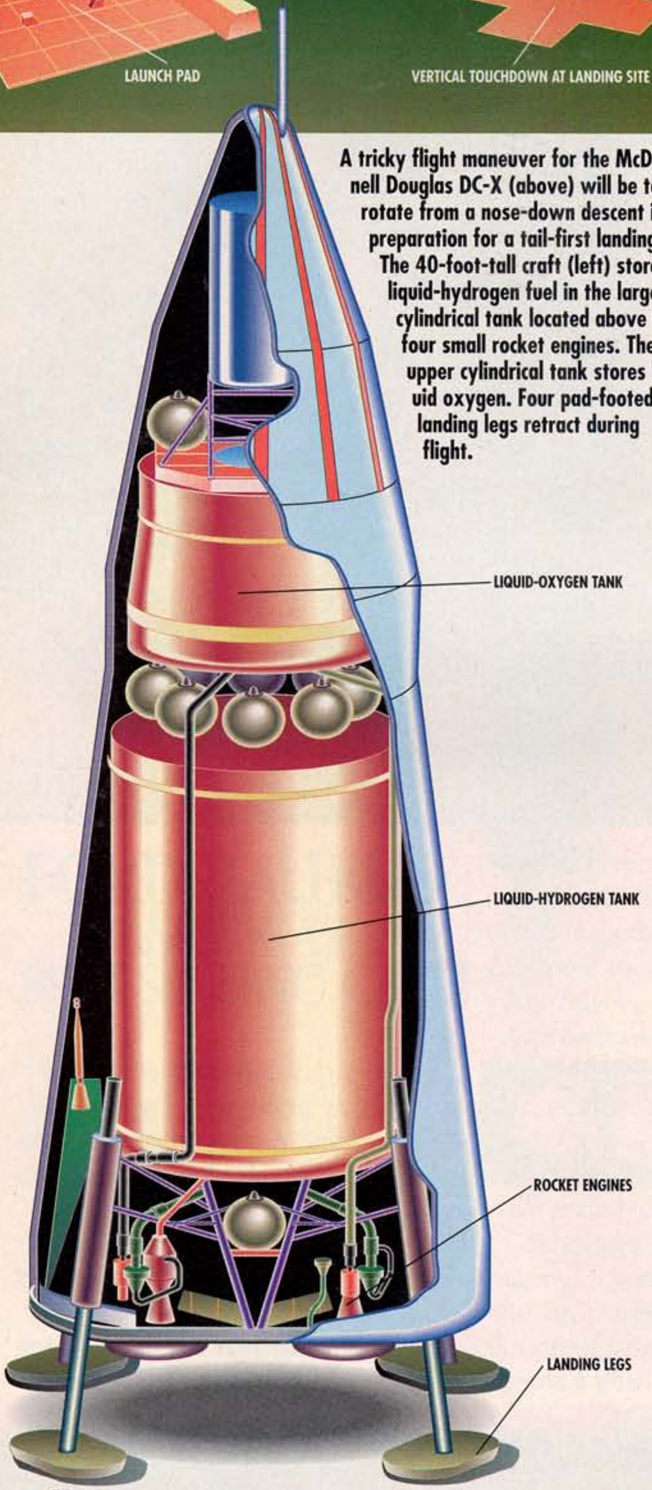
REUSABLE ROCKET SHIPS

New Low-Cost Rides to Space

A new generation of launch vehicles leapfrogs past the space shuttle and today's throw-away rockets.

BY STUART F. BROWN



A tricky flight maneuver for the McDonnell Douglas DC-X (above) will be to rotate from a nose-down descent in preparation for a tail-first landing. The 40-foot-tall craft (left) stores liquid-hydrogen fuel in the large cylindrical tank located above its four small rocket engines. The upper cylindrical tank stores liquid oxygen. Four pad-footed landing legs retract during flight.

TECHNICAL ILLUSTRATIONS BY STEVE KARP

Blasting off from the shimmering gypsum flats of the Army's White Sands Missile Range in New Mexico last September, the McDonnell Douglas Delta Clipper Experimental rocket, or DC-X, rose skyward to an altitude of 300 feet, then slowed to a startling, motionless mid-air hover—as if it were a helicopter. Tilting slightly, the craft next flew sideways for 350 feet. Finally, it began to descend tail-first. Telescoping legs with disk-shaped feet quickly extended, and the rocket used a fiery burst from its four small engines to slow down for a gentle landing. Time aloft was 66 seconds. At the strange craft's touchdown, whoops and cheers erupted from the several hundred onlookers.

Perhaps it does look like something out of Flash Gordon, a bit like a flying gumdrop. No matter. The DC-X has space scientists and engineers more excited than they've been for years. The reason: It could be the harbinger of a first in spaceflight—a truly affordable ride to orbit.

An entirely new generation of economical launch vehicles will be needed if the United States is to stay in the business of lofting commercial, military, and scientific payloads into Earth orbit and beyond. Space-launch accountants know that the major share of the space shuttle's huge cost—$500 million to $1 billion per flight, depending on whose numbers you believe—goes toward the 30,000 people who help keep yesterday's technology in operation.

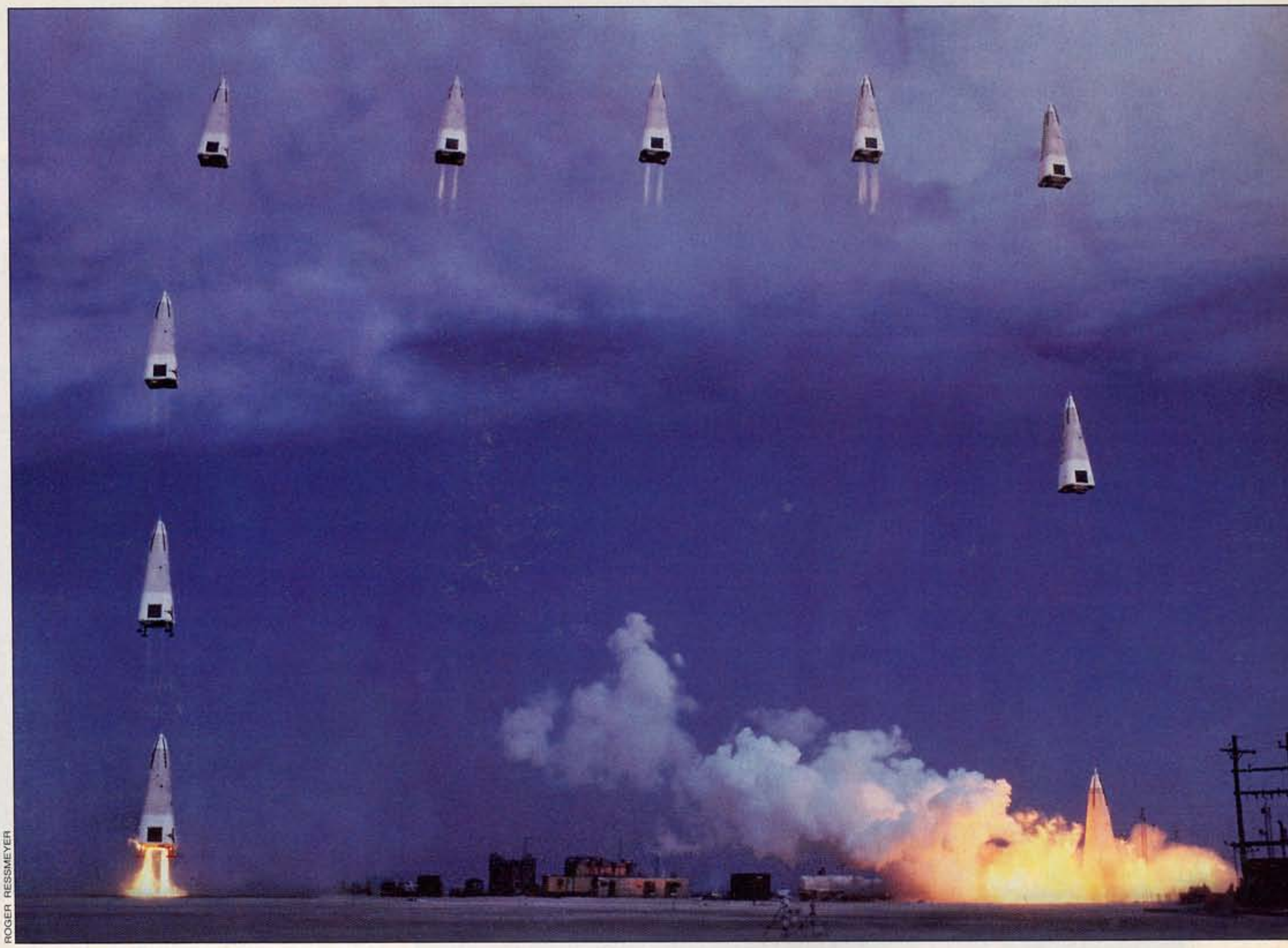
Operating costs are high, too, for the existing range of large, unmanned rockets: the Delta, Atlas, and Titan launchers that evolved from what were originally military ballistic missiles. These rockets have experienced a discouraging spate of failures in recent years, including last summer's $2 billion explosion of a Titan IV carrying a payload of spy satellites.

Designers hope future craft derived from the one-third-scale DC-X test rocket (one-third the size of a hypothetical craft capable of full orbital missions) or other new launcher ideas being explored will reduce the cost of orbiting a pound of payload to as little as $500. The government anticipates launching about 39 payloads weighing 25,000 pounds each from 1995 to the year 2030. With the current fleet of rockets, the cost of those launches would add up quickly, at $3,000 to $10,000 per pound.

The reusable, single-stage-to-orbit (SSTO) idea represented by the Delta Clipper program has appeal partly because it avoids throwing away expensive hardware, such as the lower-stage engines and fuel tanks used in conventional rockets. But greater cost savings would come from conducting airliner-type operations: Rockets would be serviced, refueled, and quickly relaunched by ground crews that are unthinkably small by current standards. Because it has been built and repeatedly flown, the DC-X is the most visible result of a race to develop a spacecraft that will dominate the world's launch market by getting the job done more cheaply than its competitors can.

Access to Space, a review of the nation's launch-vehicle needs, is being carried out by an interagency group with members from NASA, the Department of Defense, and the Department of Transportation. The team is evaluating several generic advanced-technology launcher designs, including an SSTO rocket, an SSTO air-breathing rocket based on the X-30 national aerospace plane (NASP), and a two-stage-to-orbit (TSTO) combination of an air-breathing first stage and a rocket-powered second stage. It appears that any of the systems could be made to work and could cut space launching costs to 20 percent of their current levels. The TSTO represents a lower-risk, moderate-performance option, while the SSTO concepts are higher-performance alternatives that involve greater technical risks.

In general, the government describes its launching needs



ROGER RESSMEYER

to a group of aerospace firms, leaving them free to develop launch-system proposals based on their individual engineering philosophies and areas of expertise. A winnowing process identifies any technology-development efforts needed to make the most promising ideas work and gets the research rolling. Then an experimental version of the best design is flight-tested and developed into a new national launcher relying on the most advanced technology.

DC-X IN ACTION

The flight of the DC-X experimental rocket is shown in this multiple image. Takeoff occurs in the lower right-hand corner. A bank of remotely triggered cameras located a few hundred feet from the rocket captured the craft at ten points along its flight path, at approximately eight-second intervals. The ten frames of transparency film were digitally scanned and then composited on a Macintosh Quadra 950 computer. The completed image fills 79 megabytes of disk space, and was transferred onto eight-inch by ten-inch transparency film using a Kodak LVT laser film recorder.

In addition to the Delta Clipper's vertical-launch-and-landing concept, four alternative reusable launcher designs have been proposed. If funding can be found, more than one of these ideas may be developed to see which holds the most promise. They are:

• A winged SSTO rocket that would take off vertically from a launch pad, then glide back for a runway landing. This option carries the extra weight of stubby wings and landing gear rather than the extra fuel a Delta Clipper-style rocket needs to slow itself for a tail-first landing.

• An air-breathing SSTO that would use a small rocket at the end of its runway-based flight to orbit. The ailing X-30/NASP program [see "Whatever Happened to NASP?"] seeks to develop a craft that would avoid the need to carry large on-board supplies of liquid oxygen by using ramjet and scramjet engines burning hydrogen mixed with atmospheric air.

• A vertical-launch, runway-landing, wingless lifting-body design. Lockheed Corp., which is working on the craft, calls it an aeroballistic rocket. The craft's wide aft end would house several rectangular rocket-propulsion units of a type known variously as linear, plug-nozzle, or aerospike engines.

• A runway-based TSTO launcher, which Boeing and NASA have been studying. Boeing's concept uses a large mothership powered by advanced jet and rocket engines to carry an underslung, NASP-like orbiting craft. A NASA configuration puts a rocket-propelled orbiter on top of a mothership powered by turbofans and ramjets. A precursor to both is Germany's Saenger, which features a large Mach 6 turbo-ramjet craft with a small rocket-powered orbiter on its back.

Nobody knows yet whether today's technology can make SSTO flight a reality. Going to space is governed by the physics of rocket science, in particular by a rule known as the rocket equation. According to veteran rocket designer Max Hunter, a longtime SSTO proponent and consultant on the DC-X: "The equation says the amount of high-energy propellant you have to carry to reach orbit works out to about 90 percent of the vehicle's takeoff weight, which leaves only 10 percent of takeoff weight for the rocket's structure and payload."

To make room for a useful payload, designers have traditionally built rockets in multiple throwaway stages, each with its own engine and fuel tank. "The only reason for staging was that we couldn't build a light enough structure that could carry all the propellant," says Hunter.

New lightweight materials promise to keep the structural portion of a rocket's takeoff weight low enough so that the craft may be able to lift a payload into orbit with only a single stage. Early aerospace metal alloys used in rockets 20 or 30 years ago have been improved. A weight-saving aluminum-lithium alloy is now available, for example. So are more exotic materials, such as the heat-tolerant titanium metal-matrix composites developed in the NASP program. Modern materials like carbon- and aramid-fiber composites can also be used in interior structures, where temperatures remain in the moderate range.

Using advanced-design rocket engines with high internal temperatures and pressures [see "New Engines for New Rockets"] is the second way designers can push toward meeting the tough goal of fully reusable SSTO rockets. High-performance engine options include a modified version of the powerful space shuttle main engine, a novel "tri-propellant" engine built in Russia, and the promising aerospike design that Rocketdyne and Aerojet have worked on.

McDonnell Douglas was chosen to build the DC-X after a competition in which four aerospace companies submitted designs. The project's $67 million price was paid by the Ballistic Missile Defense Organization (BMDO, formerly known as SDIO and nicknamed "Star Wars"), which has an interest in promoting research that could cut the cost of launching missile-intercepting payloads. Air Force Col. Simon Worden, BMDO's deputy for technology, has made it clear, however, that the money to build the follow-on rockets needed to prove or disprove SSTO's practicality will have to come from somewhere else.

Hovering, maneuvering laterally, and braking its descent with rocket thrust were critical technical milestones for the 40-foot-tall DC-X, the

NEW ENGINES FOR NEW ROCKETS

Reusable launchers will need lightweight, highly efficient engines to reach orbit. One candidate is an industrial-strength version of the space shuttle's main engine (SSME). The highly stressed hydrogen- and oxygen-burning Rocketdyne SSMEs are the world's most efficient rocket engines, but they need a major overhaul after each flight to ensure safety. Beefing up the engine's structure, while reducing performance somewhat, could make it reliable for multiple flights without extensive maintenance.

Russia has a contender, too. The "tri-propellant" RD-701 engine built by NPO Energomash is designed to burn a combination of liquid oxygen, kerosene, and liquid hydrogen during the first phase of flight. Kerosene, a dense fuel that produces high thrust to accelerate the fuel-heavy vehicle at takeoff, can be stored in smaller, lighter tanks. During the climb, the engine switches to hydrogen, a fuel that expands into exhaust at higher efficiency because of its much lower molecular weight. The RD-701 has been ground tested, but not yet flown, and needs further development.

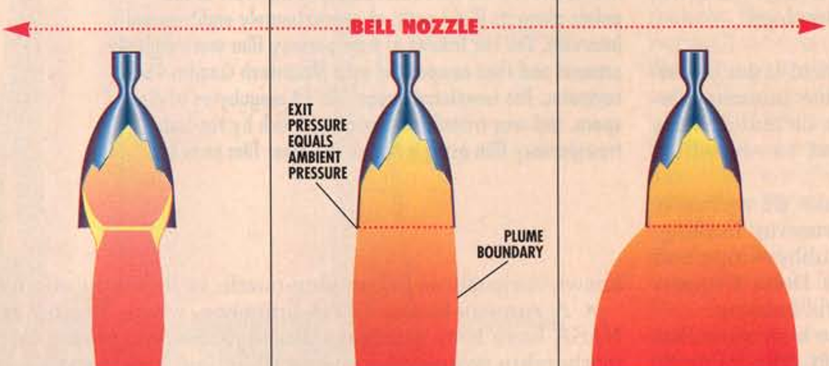
A third candidate is the aerospike engine, which replaces the traditional bell-shaped exhaust nozzle with a flat-bottomed inverted cone surrounded by a ring of combustors. A rocket engine's exhaust nozzle controls the expansion of its combustion gases, ideally producing a straight-edged column, and sends the resulting thrust force upward into the vehicle. Bell nozzles produce an exhaust flow that changes shape during flight, as pressure varies from the atmosphere at sea level to the vacuum of space. Thus, the designers must choose a compromise shape that's best at only one point during the rocket's ascent.

The aerospike engine uses shock waves and changing ambient air pressure during the climb to maintain an optimal expansion ratio. "It's an altitude-compensating nozzle without any moving parts," says Rocketdyne director of advanced programs Hank Wieseneck, one of the engine's developers.—*S. F. B.*

Running in dense sea-level air, high ambient pressure maintains efficiency by restricting the expansion of the engine's exhaust plume.

As the rocket climbs through its optimal design altitude, the exhaust flow roughly equals its diameter.

At high altitudes and low ambient pressures, the exhaust plume is bound at its perimeters by shock waves that direct its flow straight downward.



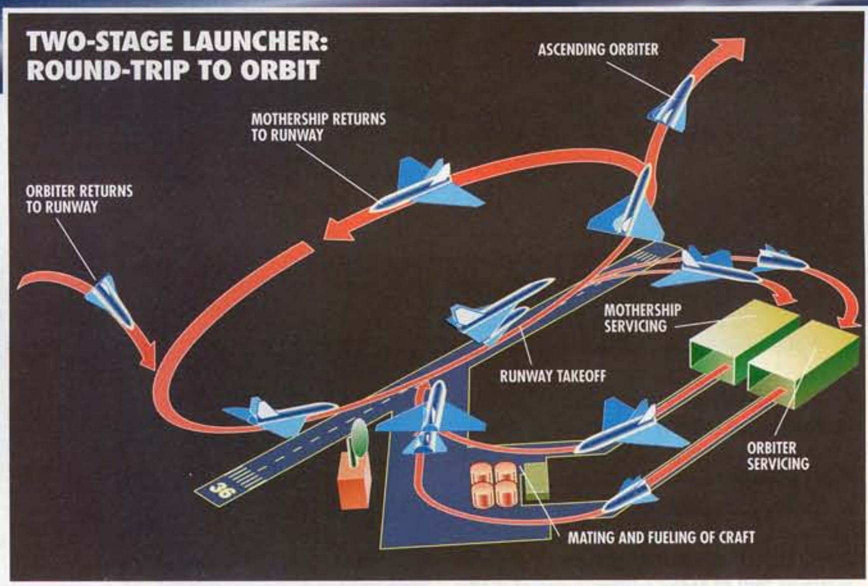
At sea level, a bell-nozzle engine's exhaust plume is pinched by high ambient air pressure, reducing its efficiency.

When the engine's design altitude is reached, the bell nozzle produces an efficient column-shaped exhaust plume.

As the rocket ascends past its design altitude, the exhaust plume flares and again becomes inefficient, this time due to overexpansion.

P_a=Ambient Pressure P_d=Design Pressure

The Boeing Company proposes a two-stage-to-orbit (TSTO) launching system that would carry an orbital craft nested in the belly of a mothership (below) to a high-altitude launch point. The mothership Boeing suggests uses six high-thrust turbojet engines and a single rocket engine borrowed from the space shuttle and mounted between the twin tails. The orbital craft shown at left separating from the first-stage craft is based on the X-30 national aerospace plane design.



Boeing's operational chart (right) shows the servicing, mating, and fueling of the two-stage launch system in preparation for launching from a runway.

product of a program begun barely two years ago. "The bird flies well, and landed right on the center of the pad," reported the flight test manager, former Apollo astronaut Pete Conrad, beaming. "Some of the heat-protective paint turned black, so we'll take the hose and soap and wash it. Then there's no reason not to run it for several more flights to accomplish all the objectives we can with this vehicle."

Further suborbital tests will keep the DC-X airborne longer and take it as high as 16,000 feet. And if someone commits more money, another, larger test craft will be built—the second phase of a three-part effort to build a fully reusable SSTO rocket that can carry people and payloads into space. According to Paul Klevatt, DC-X project director at McDonnell Douglas, "The next step will be a vehicle twice the size of DC-X, which could be flying up to 100 miles—a real space environment—by the summer of 1996." Congress would have to provide several hundred million dollars to build the second-generation test craft, he says.

If the program continues, the technical obstacles will grow more forbidding. DC-X is in the process of demonstrating takeoff and landing, stability and maneuverability, and flight control—directed by a crew of just three, housed in a small, portable operations center. But only about 50 percent of its weight is devoted to liquid-hydrogen and oxygen propellant; its outer body, or aeroshell, is made from a carbon-composite material intolerant of atmospheric heating at supersonic velocities. That limits the first-generation DC-X to airliner-like speeds and altitudes.

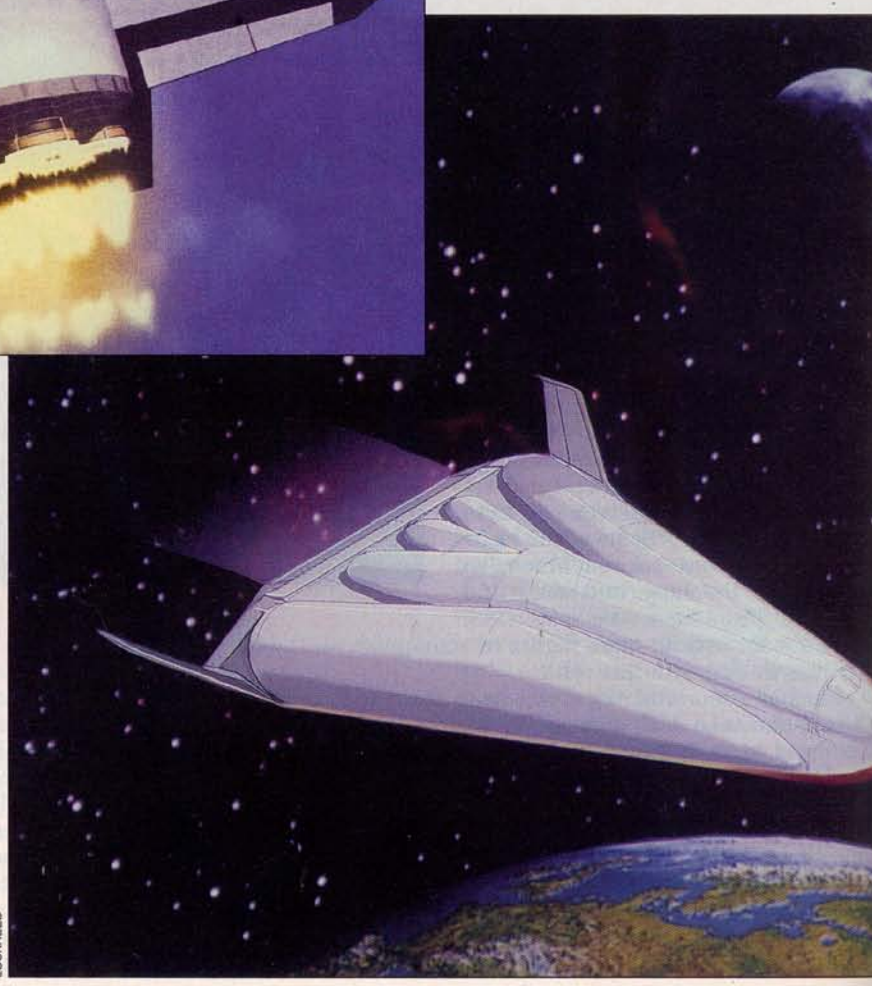
One of the goals for a follow-on experimental craft is to use different materials and lighter designs to improve the fuel portion to at least 70 percent of takeoff weight, according to Maj. Jess Sponable, DC-X program manager at BMDO. Another, he says, is to demonstrate a thermal-protection system during high-speed, high-altitude suborbital flights that will generate many of the aerodynamic and heating stresses of reentry from orbit. One key maneuver will have engineers biting their fingernails: safely flipping the craft end-for-end from its nose-down reentry attitude in enough time to fire the rockets for a tail-first landing.

Meanwhile, McDonnell Douglas is looking ahead to a third-generation craft called the DC-Y. A 130-foot prototype orbital rocket weighing about 1.3 million pounds at liftoff, the DC-Y would be able to put a 20,000-pound payload into low Earth-orbit, fly home in one piece, then repeat the feat in a matter of days rather than weeks or months.

NASA, previously unsupportive of SSTO rocket research, has been jolted by the successful DC-X flights into setting up a study called X-2000, which may lead to the development of its own single-stage rocket. Or, the agency might decide to step in and support the continuation of the Delta Clipper effort. Regardless of what NASA does, the Defense Department's Advanced Research Projects Agency and the Air Force, which launches many intelligence and communications satellites, will probably make sure the program doesn't die of starvation.

Backers of two-stage reusable launchers, such as the system proposed by Boeing, argue that the design allows for the weight growth that almost all flying craft experience during their development, without demolishing the launcher's payload-carrying ability.

Boeing's idea is to build a large mothership that would sprint briefly from a runway to an altitude of about



LOCKHEED

NASA's single-stage-to-orbit concepts include a winged rocket (above) that would glide home to a runway landing. Lockheed Corp.'s Skunk Works advanced development group has drafted detailed plans for what it calls an "aeroballistic rocket." With an unpiloted lifting body design (right), the craft would carry a payload matching that of today's Titan IV rocket in the raised area along its centerline. Liquid hydrogen fuel is stored in the bulges on both sides, with liquid oxygen stored in a trident-shaped tank behind the payload. Lockheed isn't releasing drawings showing the linear aerospike engines arrayed across the launcher's aft end.

100,000 feet and a speed of Mach 3.3. It would then let loose a NASP-like, ramjet-scramjet-powered orbiter nestled beneath its belly. With that free ride, the orbiter wouldn't have to carry the additional propulsion hardware and fuel needed to accelerate from a dead stop on the ground. The mothership would use advanced jet engines being developed in NASA's high-speed civil transport program. Before takeoff, the two unfueled vehicles would be towed into position by airport-style tugs, then mated and fueled. Both craft would be supported by the mothership's landing gear during takeoff, permitting the orbiter to have extra-light gear sufficient for landing with nearly empty fuel tanks.

"I believe that the NASP isn't going to be able to achieve SSTO," says Richard Hardy, vice president of Boeing's military airplanes division. "We feel the NASP guys should think of themselves as a second stage that starts flying at Mach 3, and let us solve the low-speed propulsion problem for them. About 5 percent of the NASP design's weight is landing gear, and that could be what eats up the payload."

David Urie, Lockheed's director of high-speed and space projects, recalls how the idea for the vertically launched aeroballistic rocket came to him. At the time, he was using a company-developed computer program to generate a series of possible shapes for the Assured Crew Return Vehicle, a proposed craft that would rescue and bring home space station crews in an emergency. Some of the wingless, lifting body shapes generated had a thick and wide aft edge.

"I had an 'aha!' experience when I was looking at one of those shapes, because I realized it was a perfect place to put a row of linear aerospike engines," he says. Using six or seven of the rectangular, high-efficiency engine modules would give the craft the means to fly back to a runway landing even if one or two failed.

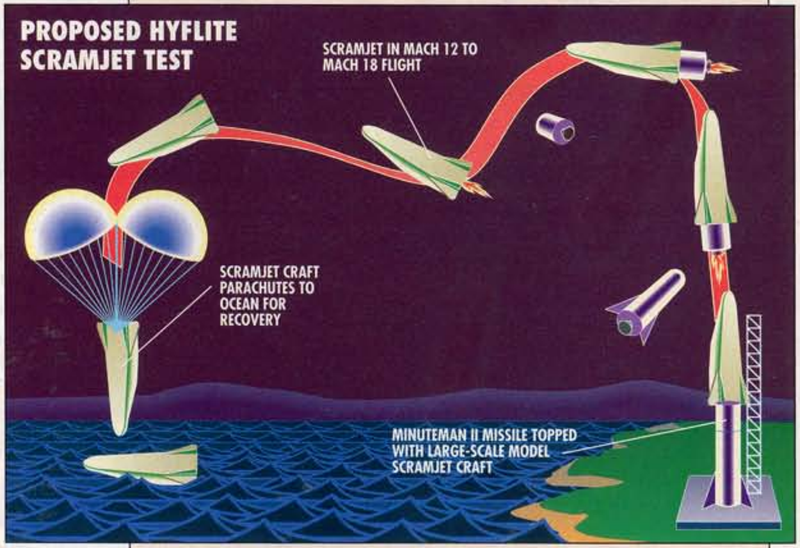
The linear aerospike design works on the same principles as a circular, aerospike engine [see "New Engines for New Rockets"]. A concept that has been extensively tested on the ground, it is arranged as a rectangle that ejects exhaust gas through slots at its top and bottom edges. A truncated rectangular spike located between the slots guides the expansion of the gas flow.

Urie says the linear engines offer weight savings through overall structural efficiency. By feeding fuel into the upper and lower rows of combustors at different rates, the engines can control the craft's pitch angle without the added hardware required to gimbal a conventional rocket engine.

For McDonnell's hoped-for DC-Y to be a winner, the designers must single-mindedly wrestle with the demon of the rocket equation to squeeze in a fuel load accounting for 90 percent of weight at takeoff. Mere grams will count. The engineers know full well that it's better to stay home in bed than let structural weight grow even a sliver of a percent too much—and end up with a rocket that won't make it all the way to orbit, or can't do it with a payload that pays off.

The same harsh equation confronts design teams at Lockheed and any other organization that takes on the SSTO challenge. Is today's aerospace engineering up to it? Maybe two-stage designs—or even a new generation of multistaged, throwaway rockets built with inexpensive, low-tech components—will turn out to be the next way to fly. In the aerospace game, it's nothing ventured, nothing gained. PS

WHATEVER HAPPENED TO NASP?



One of the most challenging aerospace research efforts ever has been largely discredited and appears to be headed for a crash landing. The X-30/NASP (national aerospace plane) program aims to build a craft that would use an exotic ramjet-scramjet propulsion system. (A scramjet is a ramjet that burns hydrogen mixed with supersonic air flowing through it.) Inhaling atmospheric air, it would fly to very high altitudes and the incredible speed of about Mach 18. Then a rocket would provide the final nudge into orbit.

After several years and an investment of $2 billion, NASP funding is expected to be cut by about $20 million in 1994. Useful gains in materials science and other areas have been made, but while an aerospace plane was described and promised, key systems—the engines in particular—are still just laboratory items.

Ben Rich, former president of Lockheed Advanced Development Co. and an expert in high-speed flight, is among those who are skeptical about scramjets. "Nobody has shown me numbers saying that a scramjet has generated net propulsive thrust," after you factor in the steep aerodynamic drag inherent in such engines, he says. The NASP has also met cynicism from overseas. At a 1992 aerospace plane conference, Heinz Pfeffer, head of the European Space Agency's directorate for transportation, said, "NASP is a cover for Aurora [a rumored hypersonic spy plane]. Aurora has achieved its goals and NASP can be allowed to fizzle out."

Nonetheless, some sensible hypersonic testing of technologies needed for the NASP may still take place under a revised research strategy. Jim Mattice, assistant undersecretary of the Air Force for research and engineering, cites a proposed test series called Hyflite [see illustration]. It would culminate in boosting a 30- to 40-foot scramjet-powered subscale test model of an X-30 atop a surplus Minuteman II ballistic missile for a few minutes of Mach 12 to Mach 18 flight. The goal of the six-year, $2 billion series of nine or ten test flights: reducing propulsion, aerodynamic, and atmospheric-heating uncertainties before building a full-size aerospace plane. One of the conclusions drawn from the Hyflite experiments "could be that this is too hard to do," Mattice says. "But I would say that the chances of the program being successful are greater than 50 percent."

Subscale tests like Hyflite still wouldn't solve the problem of how to flight-qualify a full-size scramjet for service in a manned craft in the same manner jet engines are proven. However, two-stage-to-orbit designs can use a first stage powered by turbofans and ramjets—both well-understood engines. Swapping a scramjet for a ramjet module and flying the craft at its maximum speed would be a way to gain hours of real-world experience. Scramjets and the air-breathing SSTO idea still have backers who believe the potential benefits are too great not to be explored.—*S. F. B.*