NO GO-AROUND

NASA/JOHNSON SPACE CENTER

Like the moon floating serenely across the sky, a spacecraft in Earth orbit is in a constant struggle to escape gravity and streak boundlessly toward outer space. It is an exquisite blend of forces that allows an orbiting projectile to free-fall toward our planet at exactly the same rate at which the Earth's curvature falls away. Such is the magic of orbital mechanics. ■ While sailing in silence above the atmosphere where one can watch meteors burning below and where there is virtually no drag or weight, a NASA orbiter, which is about the size of a Douglas DC–9, can be made to assume any attitude without regard to its flight path. The nose can be pointed straight up and belly forward, straight down in knife-edge flight, or in any attitude in between. ■ Attitude in space is controlled by an autopilot or by a human pilot using a

You have only one chance to land the space shuttle

BY BARRY SCHIFF

PHOTOGRAPHY BY MIKE FIZER

An orbiter's cockpit has the general appearance of an airliner's, but many of the controls are unfamiliar.

short control stick called a *rotational hand controller*. As in conventional airplanes, the stick is moved left and right to control roll, and fore and aft to control pitch. It is twisted clockwise and counterclockwise, however, to control yaw.

Aerodynamic flight controls obviously are ineffective in space. Moving the control stick signals a combination of control jets to operate. These are small rockets that make the orbiter roll, pitch, and yaw. There are 44 such steering jets on the shuttle, 16 on the nose and 28 on the tail.

The runway at the Kennedy Space Center in Florida is half a world away, one hour from touchdown, and we are about to vacate circular orbit, which can be a minimum altitude of 100 nm msl and a maximum of 312 nm. The orbiter is turned tail first, its nose pointed opposite to our direction of travel. Two 6,000-pound-thrust rocket engines are fired for two to three minutes, and the orbiter responds with a speed reduction of 118 to 326 knots (depending on orbital altitude). Tugging relentlessly, gravity finally wins the struggle. The orbiter begins an initially gradual descent.

An orbiter's cockpit has the general appearance of an airliner's, but many of the switches and controls have unfamiliar markings and labels. Patches of Velcro are glued everywhere, handy places to secure small objects that would otherwise float about the cockpit during orbital weightlessness. The commander, who makes the landing, sits on the left, while the pilot (who is really the copilot) sits on the right.

As in most aircraft, the primary instrument for monitoring attitude is the attitude indicator. The AI in an

PHOTOGRAPHY BY MIKE FIZER

orbiter, however, is much more sophisticated than those found in most other aircraft. It consists of an enclosed sphere (colloquially called an *eight ball*) that is gimbaled to display movement about all three axes.

A three-cue flight director (called *guidance needles*) is contained within the attitude indicator to command computer-generated roll, pitch, and yaw control inputs.

Touchdown (T) minus 32 minutes 14 seconds, 14,800 knots (TAS), 400,000 feet msl—We encounter the upper fringes of the atmosphere (entry interface) 4,200 nm from destination. Sink rate is 30,000 fpm. The orbiter begins to make the transition from a spaceship to a glider. The steering rockets are now used to establish zero roll, zero yaw, and a typical angle of attack (alpha) of 40 degrees.

The angle at which the shuttle enters the atmosphere is critical. If it is excessive, the glider could skip off the top of the atmosphere like a flat rock off of water or stall as the increasing air density takes a firmer grip. Recovery from either event is unlikely. Too small an angle of attack results in excessive speed and frictional heating that can damage the leading edges of the wings. Damage also can result from excessive dynamic pressure and G-load.

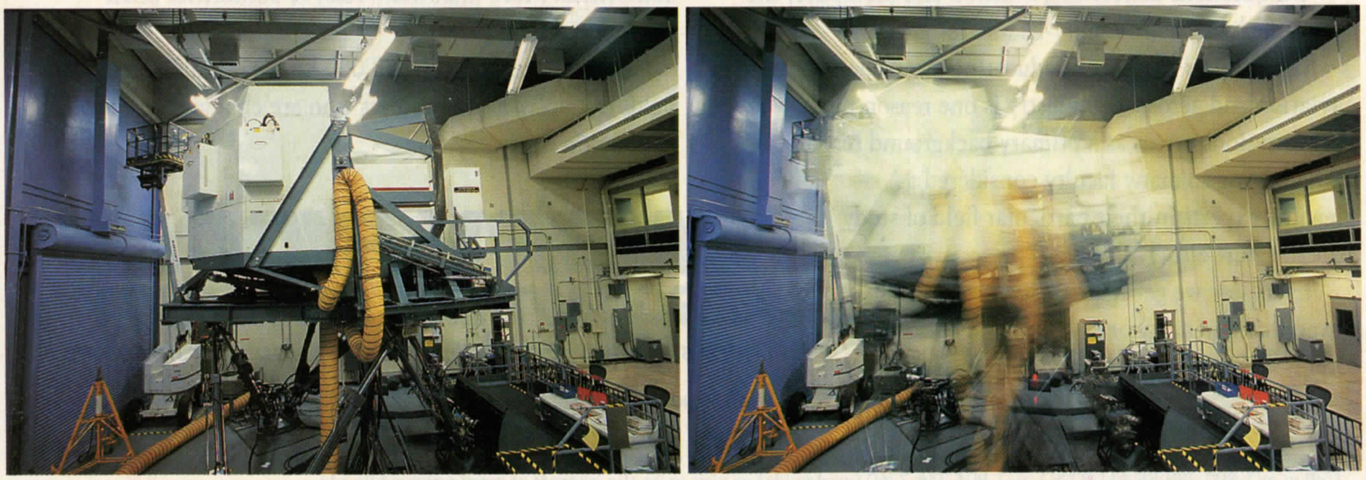
T minus 28:42—The orbiter has four hydraulically actuated elevons, two on the trailing edge of each wing. These combine the pitch and roll functions of elevators and ailerons and are commonly used on delta-wing aircraft. The elevons start to become effective at an indicated airspeed of 25 knots, which occurs between 250,000 and 280,000 feet. Most of the steering rockets are deactivated when the elevons become fully effective at 108 knots.

T minus 26:56—The flight directors give the first roll commands for the purpose of steepening the descent profile when on-board computers sense that the orbiter has too much energy (altitude). Rolling steeply left and right reduces the vertical component of lift, which increases sink rate. Rolling increases skin temperature, but not as much as would lowering the nose (decreasing alpha) and increasing airspeed. Roll maneuvering results in very little heading change because the turn rate at such high airspeed is so minimal. The pilot and commander monitor the actual versus desired descent profiles on one of the CRT displays on the main instrument panel.

T minus 26:04—Our glider is descending at Mach 19.0 to 25.0, and the friction of the atmosphere causes skin temperatures to peak. During hypersonic flight (more than Mach 5.0), the aircraft has a glide ratio of 1.05:1; at subsonic speeds, it improves dramatically to 5.1:1, a far cry from a typical jetliner's at 20:1 or a retractable piston single at 10:1.

Although an autopilot normally makes the descent from orbit and is used to enter the atmosphere, it also is capable of making the entire approach and landing. Shuttle commanders enjoy the little actual flying involved in a shuttle mission and typically take over manually at Mach 1.0. When hand-flying an orbiter, a pilot never needs trim because the fly-by-wire control system automatically displaces the control surfaces as necessary to obviate the need for trim. (A manual backup trim also is available.)

NASA's full-motion simulator pitches up almost 90 degrees during the simulation of a launch, and the visual system allows the crew to view the receding gantry from the left front window.

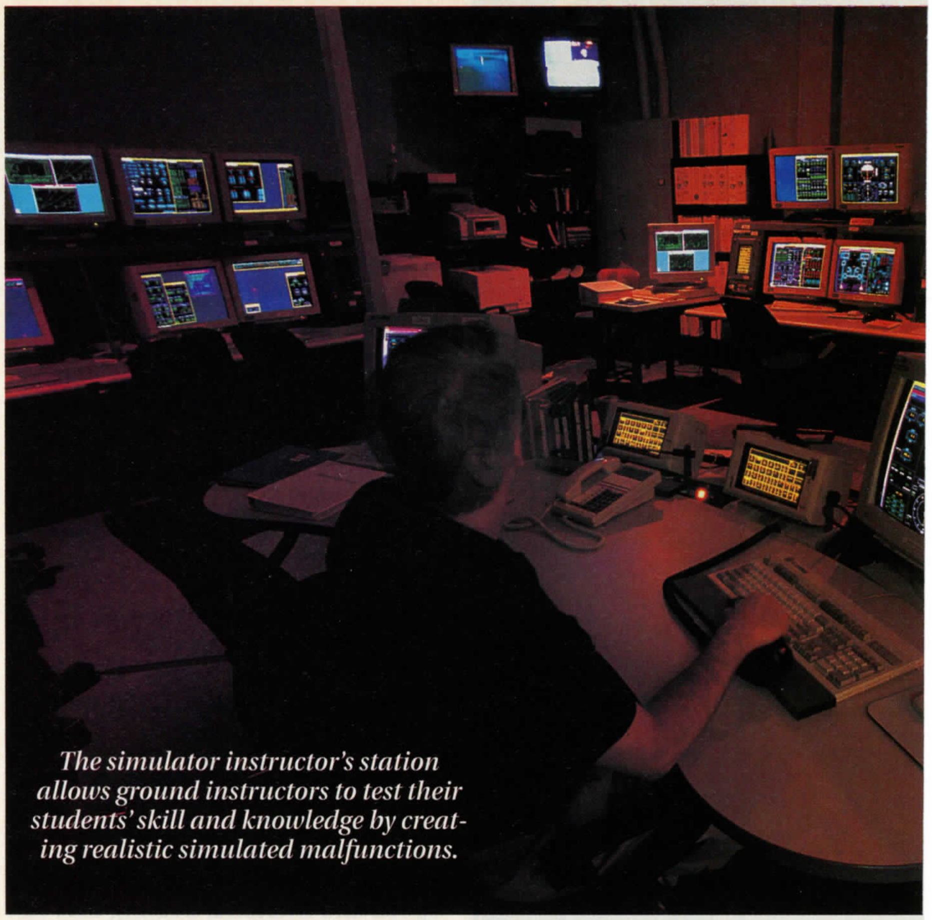


T minus 12:54—The angle of attack gradually begins to decrease, and the speed brake opens to 81 percent. The speed brake is incorporated into the rudder, which is made to split open along its trailing edge.

T minus 10:33, Mach 7.3, 142,000 feet—The aircraft has been guided by inertial navigation, but now the destination TACAN (the UHF military equivalent of a vortac) is within range and will be used for guidance during most of the arrival.

T minus 8:44, Mach 5, 120,000 feet—The dual, relatively fragile pitot probes are deployed from the fuselage. Had they been extended earlier, they would have overheated, softened, and failed. The rudder, which previously had been blanketed by the large angle of attack of the wings, is now activated. It automatically compensates for adverse yaw effect, acts as a yaw damper, and provides rudder trim as needed. The remaining control rockets, which have been used to control yaw, are now deactivated.

T minus 6:44, Mach 2.6, 83,000 feet—Control guidance has thus far been provided by the dual flight directors. But now the head-up displays (HUDs) are



The simulator instructor's station allows ground instructors to test their students' skill and knowledge by creating realistic simulated malfunctions.

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The HUD (head-up display) is an easy-to-use flight director; very much like a sophisticated video game.

activated. Each is a transparent panel that is situated in a pilot's field of vision as he looks out the front windshield (like a sun visor). The pilot looks through the HUD to see the outside world while simultaneously viewing a plethora of performance and status data that is holographically displayed on the HUD.

Two of the many symbols on the HUD are of particular interest. One represents the velocity vector of the orbiter and shows where the aircraft is going. The other shows where the computers want the aircraft to go. The pilot's job is to roll and pitch the aircraft so as to superimpose one symbol on the other so that the actual path of the aircraft coincides with what the computers want. If the computers want the pilot to lower the nose and turn left, for example, one symbol moves down and toward the left, and the pilot responds by moving the controls so that the second symbol "catches up" with the other. It's essentially an easy-to-use flight director, an extraordinarily sophisticated video game. More good news is that the pilot does not have to worry about airspeed. As long as he follows the pitch and roll commands issued by the HUD and the flight director, airspeed takes care of itself.

T minus 3:57, Mach 0.9, 46,000 feet agl—The speed brake now receives computer-generated commands and modulates automatically to manage airspeed.

The "traffic pattern" consists of joining the heading alignment cone that is tangent to the final approach course at a point seven miles from the runway threshold. HUD and flight-director guidance is provided to join the cone, which essentially leads the orbiter into a spiraling descent that leads to intercepting the final approach course. This is the last opportunity for on-board computers to manage orbiter energy. If the aircraft is too high, the pilot is given roll commands that result in widening

the turn; if the aircraft is too low, the turn is tightened. (A normal 360-degree turn results in an altitude loss of about 38,000 feet.)

T minus 1:31, 280 knots, 15,000 feet—The turn toward final approach is almost complete, and a transition is automatically made from TACAN to guidance by a microwave landing system. MLS is similar to an ILS, except that on-board computers can use MLS data to establish and display a variety of localizer and glideslope angles (as compared to the fixed localizer and glideslope of a conventional ILS).

T minus 1:14, 300 knots (IAS), 12,000 feet—We intercept the MLS localizer and roll onto the straight-in final approach. The initial reaction to seeing the runway for the first time is that there is no way to lose 12,000 feet of altitude in the remaining seven miles and still cross the runway threshold in a position to land.

Astronauts seldom have to worry about weather during an approach. Landing minimums are an 8,000-foot ceiling and a 5-mile visibility; maximum-allowable crosswind component is 15 knots (launch or landing).

We have intercepted the outer glideslope (*diveslope* might be a more accurate term), which guides us earthward at 18 or 20 degrees, depending on the orbiter's landing weight. (A normal ILS glideslope descends at only 3 degrees.) Our aim point on this segment of the descent is 7,500 feet short of the runway threshold. (If all is going as planned, the HUD symbol representing the velocity vector of the orbiter will be superimposed on this aim point.)

T minus 0:33, 300 knots, 2,000 feet—The symbols on the HUD and the flight director needles now urge me to begin a 1.3-G pull-up to make the transition from the outer glideslope to the much shallower, 1.5-degree inner glideslope. I raise the nose somewhat aggressively to recover from the 18- or 20-degree dive and superimpose the symbol representing the velocity vector of the HUD onto the runway at a point abeam the precision approach path indicator lights. This is the touchdown target and it is 2,500 feet beyond the threshold. Airspeed begins to decay from 300 to 220 knots.

T minus 0:20, 288 knots, 300 feet—The pushbuttons used to lower the landing gear are depressed. A go-around is obviously not an option should the gear fail to operate, and astronauts are not trained for a gear-up

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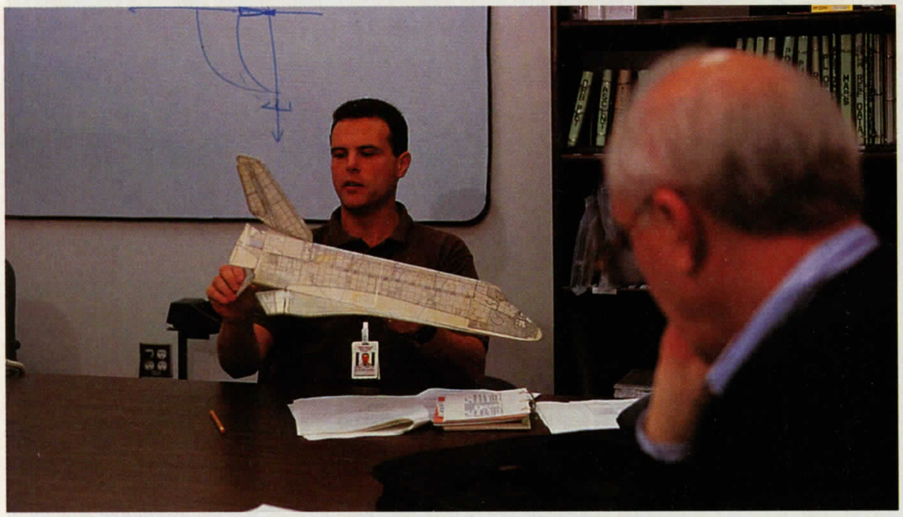


At the Johnson Space Center, NASA instructor Andrew Hamilton briefs the author about the orbitor's approach, landing, and handling characteristics (above). NASA Chief Astronaut Charlie Precourt occupies the pilot's seat (below).

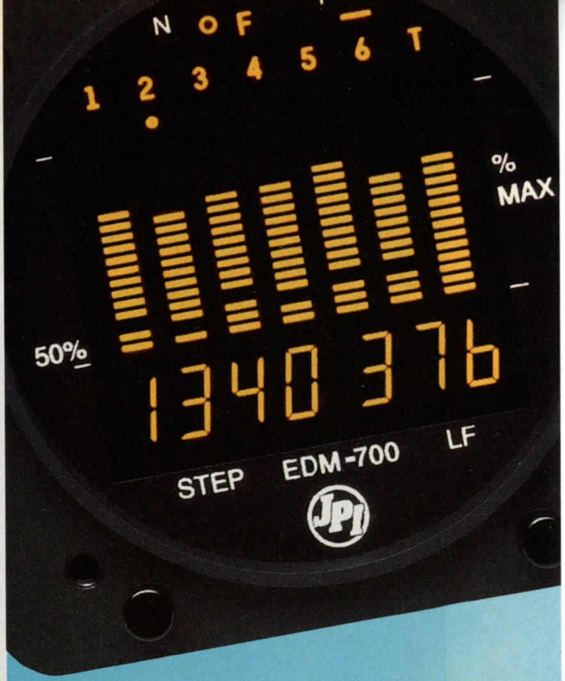
landing. NASA's philosophy is that the landing gear will operate. If hydraulic pressure fails to do the job, an automatic backup system of explosive charges will.

T minus 0:10, 261 knots, 30 to 80 feet—I raise the nose of the orbiter so as to superimpose the speed-vector symbol on the far end of the runway, which is clearly visible through the HUD. The goal is to cross the runway threshold at 26 feet. Airspeed bleeds to a touchdown speed of 195 to 205 knots, depending on gross weight.

T minus 0:00—The orbiter touches down at a sink rate of 200 to 300 fpm. The speed brake immediately deploys to its full-open position (a 99-degree rudder split), and the drag chute is deployed between 190 and 195 knots.

I begin *derotation* (NASA's expression for lowering the nose) at 185 knots with a steady application of the thumb-operated elevator "beep" trim. This lowers the nose at the desired rate without having to use any elevator input. I apply the brakes at 140 knots or with 5,000 feet of runway remaining, whichever occurs first. The toe brakes have anti-skid protection, and nosewheel steering operates conventionally through the rudder pedals. The drag chute is jettisoned at between 40 and 60 knots to prevent it from damaging the exhaust nozzles on the tail. The orbiter comes to rest in a nose-low attitude like an anteater rooting for food. The nose gear strut is unusually short to save weight.

The computers aboard the orbiter are



The training makes it possible to execute a dead-stick approach and landing without computerized guidance.

The flight deck of a Grumman Gulfstream II, which has been modified to duplicate an orbiter's descent profile from an altitude of 35,000 feet.

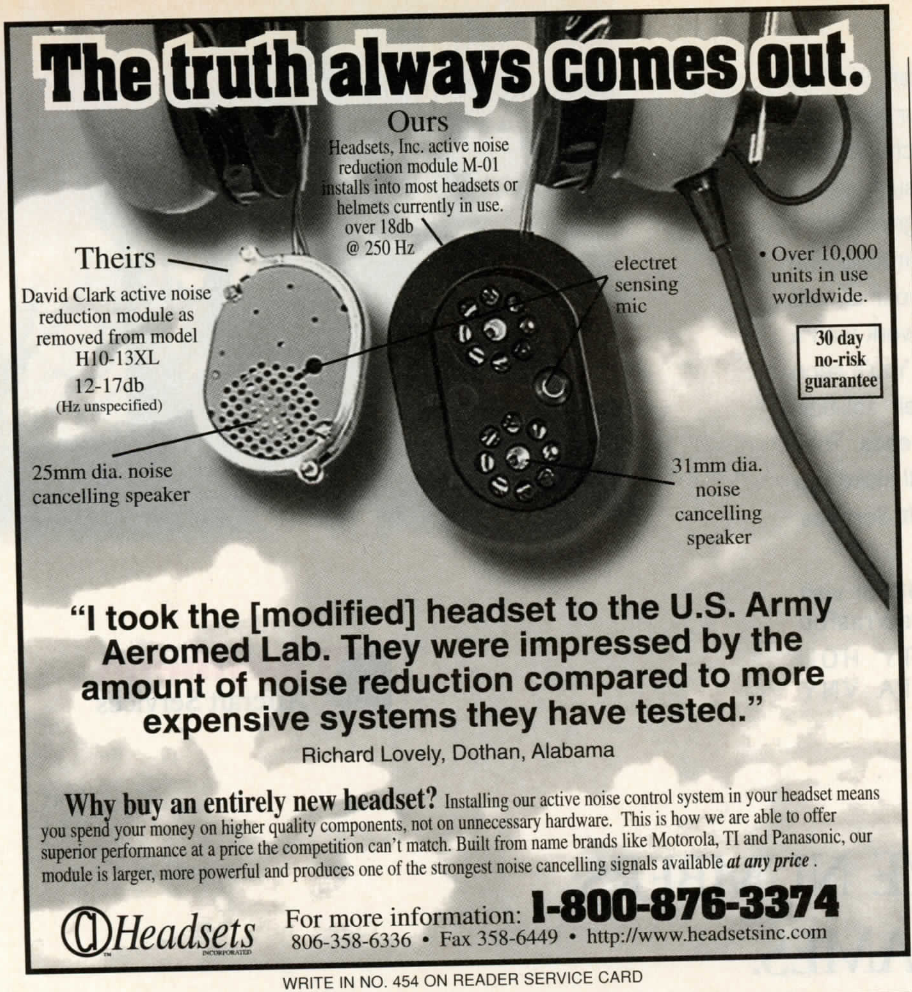
capable of establishing an approach to almost any large airport in the world (using vortac data when MLS is not available). Although the typical landing roll consumes 10,000 feet of concrete, a shuttle commander can—in a pinch—set down on a 6,000-foot-long runway.

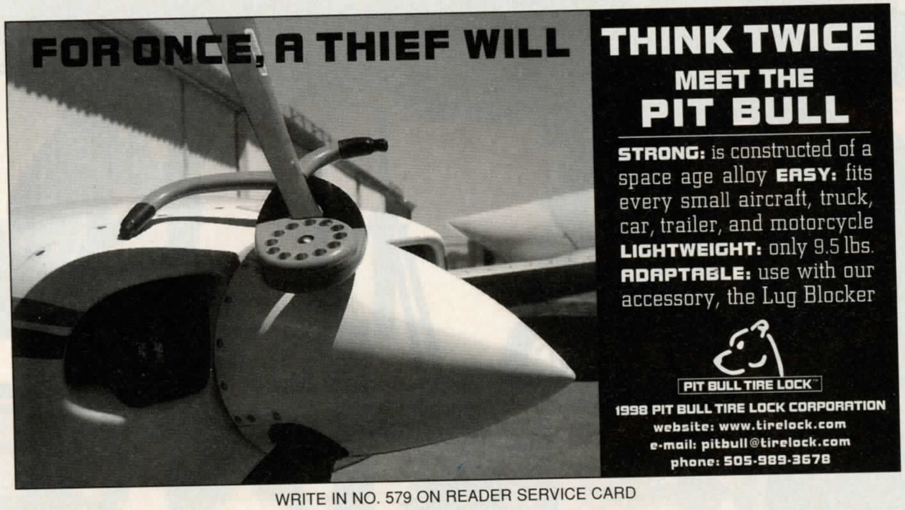
My "pulsemeter" is still pegged after this, my first landing in NASA's only full-motion orbiter simulator, which is equipped with a realistic visual system. It is at the Johnson Space Center in Houston. Astronaut Charles J. "Charlie" Precourt is seated to my right. He leans toward me and asks with a grin, "Why are you holding the brakes?" So real is the experience that I am still depressing the pedals, a habit bred during 46 years to prevent undesirable forward movement of conventional aircraft caused by idle thrust.

Precourt is NASA's chief astronaut. He was the flight engineer on STS-55, the pilot on -71, and the commander of STS-84 and -91. (STS stands for space transportation system.) A seemingly natural linguist, he also learned Russian for and did all of the docking with the Russian space station, *Mir,* during his last two missions. An avid general aviation enthusiast, Precourt also built and flies his own Rutan Long-Eze.

By the time an astronaut becomes a commander, he will have made 800 to 900 landings in the simulator and at least 1,000 approaches in the shuttle training aircraft. These are a quartet of Gulfstream IIs that have been extensively modified to duplicate the steep, high-speed approach-to-landing profile of an arriving orbiter (see "Flying the Ultimate Sim," March 1997 *Pilot*). According to Precourt, this kind of experience probably would enable a commander to make a dead-stick approach and landing without computerized guidance and energy management, although he would prefer not to have to put this theory to test. (Each orbiter has five independent guidance computers, a redundancy that makes it extremely unlikely that any shuttle commander will ever be challenged in this manner.)

Although events occur rapidly during the approach and landing, my impression is that the average general aviation pilot could land an orbiter (as long as he first receives a few hours of instruction, nothing goes wrong, conditions are favorable, and Precourt is in the right seat). Someone skilled at video games might be more adept. Arriving in an orbiter is mostly a matter of using a joystick to match symbols on the HUD. This,





however, is a simplistic view. Flying an orbiter while wearing a bulky spacesuit and coping with the effects of increasing body weight after days of weightlessness undoubtedly complicate matters.

In addition to a year of vigorous and intensive training, one of the most challenging aspects of becoming an astronaut for me would be learning NASA's acronyms, of which there are literally thousands. Two of the most amusing are WOW (weight on wheels) and WONG (weight on nose gear).

But I will not have such an opportunity, despite how this incredible experience inflamed my desire for an actual flight. Perhaps in another life. ☐

The author expresses his gratitude to astronauts Jay Apt and Charlie Precourt and NASA instructors Andrew Hamilton, Craig Newman, and David Pitre for graciously sharing their time and experience—Ed.

Rockwell International Orbiter

Base price: $2 billion
With external fuel tank, solid-rocket boosters, and fuel: $4 billion

Specifications

Powerplants (main engines)	Three internal liquid-propellant rockets, 488,800 lb of thrust each (in a vacuum)
(Emergency thrust only)	513,250 lb
Length	122 ft 2 in
Height	56 ft 8 in
Wingspan	78 ft 1 in
Wing area	2,690 sq ft
Wing loading (landing)	95.2 lb/sq ft
Crew (minimum)	5
Crew (maximum)	7
Empty weight	175,000 lb
Maximum gross takeoff weight	265,000 lb
Max landing weight	256,000 lb
Useful load	90,000 lb

Performance

Takeoff distance, ground roll	0 ft
Takeoff distance over 50-ft obstacle	0 ft
Maximum demonstrated crosswind component	15 kt
Lift-to-drag (glide) ratio	
(hypersonic)	1.05
(subsonic)	5.1
Rate of climb (typical ascent profile)	132,000 fpm (at 130,000 ft)
Cruise speed (typical)	14,800 kt (on orbit)
Orbital altitude (min/max)	100/312 nm
Landing distance, ground roll (typical)	10,000 ft
Landing distance, ground roll (min)	4,000 ft

Limiting and Recommended Airspeeds

V_{LD} (best glide speed), sea level	185 kt (heavy)
V_A (design maneuvering speed)	185 kt (approx)
V_{LE} (max gear extended)	312 kt
V_{LO} (max gear operating)	312 kt
V_{NE} (ever exceed)	333 kt
V_{SO} (stall, landing configuration)	150 kt