Flying the Electric Skies

Airbus' A320 jetliner has sparked a hot debate over automation and safety: who really flies this airplane—the pilots or the computers?

THE NEXT TIME you find yourself flying Northwest Airlines, take a close look at the airplane that rolls up to the gate. Is it a twin-engine job with a plump, compact fuselage? Do the wings have muscular "shoulders" at the base? Do they have rakish little fins riding out on the tips?

Welcome to the A320, the world's newest and most controversial jetliner. Designed and manufactured by the European aircraft consortium Airbus Industrie, and now making its U.S. debut with Northwest after a year of operation in Europe, that plump little airplane waiting at the end of the passenger tunnel is the product of an automation philosophy so avant garde that U.S. aircraft designers have been left breathless. Indeed, the A320 has been so thoroughly computerized that it cannot fly normally without the computers.

Glance at the cockpit as you step into the plane and turn toward the cabin: your pilot and copilot don't even have steering wheels—those familiar, open-topped yokes that allow the pilots of a conventional aircraft to physically move the various ailerons, flaps, and elevators via hydraulic lines and cables. Instead they each have a one-handed joystick, or sidestick controller, that allows them to operate the airplane through a "fly-by-wire" computer network as though it were a giant video game.

As you settle into your seat, moreover, consider that an "envelope protection" software scheme will be watching over the pilots every second from takeoff until touchdown, doing its best to keep the humans from unintentionally letting the aircraft tumble out of control in an emergency, or otherwise killing you. Not without reason has the A320 been called "The Electric Airliner."

So. Feeling safer? That's exactly where the controversy begins. Just how reliable can those fly-by-wire computers really be? And just who is flying this airplane—the humans or the machines? Is the A320's preprogrammed envelope protection a major advance in aircraft safety, as Airbus maintains? Or is it, as senior test pilot John Miller of McDonnell Douglas calls it, "a tour de force of technology for technology's sake"—a rash, glitzy design that undermines the control and command authority that a pilot absolutely must have?

"The A320 is a start down the road to a whole new way of running transportation machines, whether railroads, airplanes, or whatever," says Northwest Captain Kenneth Waldrip, a Boeing 747 pilot who became a cautious enthusiast for the A320 last year when he headed a delegation to examine it on behalf of the Air Line Pilots Association. And as a result, he says, "the A320 has caused the aviation community to think a lot about *where* they are going."

Take fly-by-wire: there is something about it that gives people the willies. It is all too easy to imagine a computer failure that would leave pilots and passengers tumbling blindly through the sky in a dead airplane. As Waldrip points out, "We've all been around radios that quit, and TVs that go on the blink. And now we have this plane that can only be flown through electronics! It's caused a lot of heartburn."

To put it in perspective, he says, look back to 1958 and the first commercial jetliner, the Boeing 707. "When the pilot turned the control wheel, there were cables that ran from there all the way out to the ends of the wings. It took a lot of strength to handle the plane and it was very sluggish." For its next generation jet, the 727, Boeing added hydraulic actuators. That made the pilot's job much easier, says Waldrip, but the cables were still there as backups. Only when Boeing got to the 747 were the cables removed. "So in essence," he says, "when Airbus went all the way to fly-by-wire without hydraulics backing it up, they were skipping a step—which may or may not come back to bite them."

McDonnell Douglas certainly thinks it might, which is why the St. Louis–based company is taking a very different tack with its new MD-11, a three-engine widebody that is scheduled to start service in late 1990. The MD-11 is even more highly automated than the A320 in many ways. (Among other things, its computers will be able to diagnose equipment failures in flight and take corrective action on their own, before telling the pilots about it.) But the MD-11's computerized controls most emphatically will have mechanical backups. "The pilots have to have control in all situations, not just the normal ones," says Douglas' Miller. "A lot of what ended up in the Airbus got done because it was neat," claims Joel Ornelas, manager of the MD-11 design effort. "Engineers love it. But the pilots . . . ?"

Airbus, not surprisingly, finds such criticisms less than cogent. For one thing, say company spokesmen, fly-by-wire offers some compelling advantages: not only is the A320 some 350 kilograms lighter than it would be if it had a full set of mechanical

Airbus Industrie

Airbus' A320: The Electric Airliner.

backups, but backups that aren't there don't have to be maintained. For another, fly-by-wire isn't really all that new. The Concorde has been operating with a partial fly-by-wire system since 1969. And the A320 itself draws heavily on military fly-by-wire technology developed for fighters such as the F-16, "The Electric Jet."

But most important, says the man in charge of designing the A320 cockpit, Airbus' engineering test pilot Udo Guenzel, "we were very self-skeptical from the beginning." The result is that the A320 carries five separate computers, of which four are capable of operating the fly-by-wire system all by themselves. (The fifth provides control only in the roll axis.) The aircraft likewise has multiple independent power supplies. It uses redundant software obtained from two different vendors to minimize the possibility that the same bug will appear simultaneously. It has heavy shielding on its data cables to keep out electromagnetic interference from radio transmitters and the like—a problem that may have caused a number of crashes in military fly-by-wire aircraft. And yes, the A320 does have a partial backup system: a set of cables running back to the tail and rudder. In an absolute power failure, those cables are supposed to let the crew keep the airplane under control until they establish emergency power—or if need be, longer. "In test flights we've demonstrated [operation with the backups] from cruise flight phase to landing," says Guenzel, "which is more than they were designed to do."

The upshot of all this is that many former skeptics are now convinced that the A320's fly-by-wire system is indeed quite safe. Waldrip and his Air Line Pilots Association committee were persuaded after an extensive series of test flights last year at Airbus headquarters in Toulouse, France. The FAA, after its own series of tests, gave the A320 its certification to fly in the United States in January 1989. And even McDonnell Douglas' Ornelas, while not yielding an inch on his reservations about the design, will admit "it's not *un*safe."

However, that is not the whole story by any means. If Airbus has done a credible job of avoiding the obvious pitfalls of fly-by-wire, that just shifts people's attention to the less obvious, and thus more insidious pitfalls. Getting pilot and computer on the same wavelength, for example: the potential for misunderstanding in this particular aircraft was tragically demonstrated on 26 June 1988, when an A320 full of passengers crashed and burned during a demonstration flight at an air show in eastern France. Three people died and some 50 were injured. The formal investigation report has not yet been released by the French authorities. But according to one widespread version of the events, notes Waldrip, the pilot—the chief instructor for Air France—was making a dramatic, low-speed pass only 15 meters or so over the heads of the crowd, and may have been depending on the A320's envelope protection system to automatically boost power and fly him out of a stall. Indeed, it would have—if he had been flying higher than 30 meters. But below that point, says Waldrip, the computers will not boost power automatically because they assume the pilot is trying to land. (Ideally, an airplane should stall just as it touches down.) Before the pilot could correct the situation manually, he was in the trees.

As Waldrip recalls his delegation agreeing shortly after they finished their A320 test flights in Toulouse, "It's a dream to fly—but

Who's Minding the Cockpit?

Aircraft automation was proceeding full throttle long before the Airbus A320 appeared. Think about it the next time you are on a flight that touches down on a miserably wet, cloudy night: if you happen to be in a current-generation airplane such as the Boeing 757 or the McDonnell Douglas MD-80, both of which date from the late 1970s, the chances are that your pilot will pretty much fly hands-off the whole way. A modern autopilot coupled to a radar altimeter can handle low visibility and tricky crosswinds much better than a human can. Indeed, once a modern jetliner is airborne—takeoffs are still flown by hand—it can, in principle, navigate its way to a preprogrammed destination and land without any further intervention. And while human pilots are still essential in practice, it is true that the computers have gotten so good at monitoring the aircraft's electrical and mechanical systems that the flight engineers who used to perform that duty are essentially obsolete: every new airliner introduced since the late 1970s has been designed to be flown by just a pilot and a copilot.

However, this earlier generation of automation sparked its own share of controversy. "We started out with cockpit automation backwards," says Northwest Airlines 747 pilot Kenneth Waldrip. In the 1970s and early 1980s, he says, "the idea was that the computers would fly the plane and the pilot would monitor them in case anything went wrong. Eventually, when you thought about the design of the future, you'd have the plane out at the head of the runway, the pilot would push a button marked 'FLY,' and then he'd just watch for the rest of the trip."

There was only one problem with that scenario, Waldrip says: humans are absolutely terrible at passive monitoring. Both commonsense and rigorous psychological experiments show that, no matter how motivated and well trained they are, people get bored. Their attention flags. They start missing things. Worse, a passive pilot would often have to tackle an emergency cold, wasting precious seconds trying to figure out precisely where the aircraft was and what the automatic systems had been doing.

The upshot is that by the mid-1980s, aircraft designers, pilot trainers, and the aviation community generally had gone through a 180-degree turn in their concept of what automation should do.

The new philosophy, which often goes under the name of "human-centered" automation, was illustrated in 1980 in a seminal paper by human factors researchers Earl Wiener of the University of Miami and Renwick Curry of the National Aeronautics and Space Administration's Ames Research Center. They used the image of an "Electric Cocoon"—a concept that bears a remarkable resemblance to the Flight Envelope Protection system later implemented on the A320. In general, they said, the automatic systems would leave the crew alone to fly as they saw fit, thus allowing them to keep their flying skills sharp and to keep their attention focused on what is happening. The crew would stay actively involved with flying, and would not just serve as backups to the hardware. Only if the electronics sensed that the aircraft were approaching the boundaries of the cocoon—if it were nearing a stall, for example—would they issue a warning or take over.

Instead of having people watch the machines, in other words, human-centered automation means having the machines watch the people. It means putting the pilots firmly back in command of the aircraft—there had been some question about that, notes Waldrip—and it means putting automation back on the right track: as an assistant to the pilots. ■ **M.M.W.**

you'd better make sure that the pilot flying it understands that computer."

Even if you concede that a pilot's understanding of the airplane can be carefully honed through practice, however, he or she is still going to have to live with the A320's preprogrammed restrictions on what it will do. This guardian angel behavior, known more formally as the Flight Envelope Protection System, is widely considered by aviation professionals to be a far more revolutionary step than fly-by-wire per se. In effect, the A320's designers have decreed that their judgment about the aircraft's limits will always take precedence over the pilot's judgment. And that is not a constraint that any pilot can take lightly.

"*Nothing* must have the authority to forbid the pilot to take the actions he needs to," says McDonnell Douglas' Miller. The problem with giving away that authority to a computer, he says, is that "a computer is totally fearless—it doesn't know that it's about to hit something."

Imagine, for example, that an A320 pilot makes a sharp turn to avoid an imminent collision, or else dives and then has to pull out to avoid the ground. No matter how desperately he or she hauls back on that sidestick, the envelope protection system will not let the airplane respond beyond a certain rate: namely, the rate that limits stress on the airframe to 2.5 times the normal force of gravity (2.5 G).

Airbus Industrie

A320: The pilot's view. *Mechanical dials and gauges have given way to color CRTs; "steering wheels" have given way to sidestick controllers.*

On the face of it this seems like plenty. Getting to 2.5 G would actually require quite a violent maneuver, with a normal adult feeling a weight of more than 400 pounds at the peak. But consider what happened to China Airlines flight 006 on 19 February 1985. While cruising at 41,000 feet some 300 miles northwest of San Francisco, on a flight from Taipei to Los Angeles, the 747 suffered a partial loss of power in the right outboard engine. Leaving the airplane on autopilot, the captain and crew focused their attention on getting the engine restarted—and in the process, failed to notice that the autopilot's effort to compensate for the drag of the stalled engine was tilting the airplane further and further to the right. By the time they realized what was happening, the 747 was falling out of control into a near vertical dive. Over the next three minutes it plunged nearly 6 miles, until the captain was able to maneuver it back into level flight at only 9500 feet. He measurably warped the wings. He caused several million dollars worth of other structural damage. But he saved the airplane and passengers. And to do it he had to pull an estimated 5.5 G, or more than twice the A320 limits.

Airbus, not surprisingly, responds that an A320 never would have fallen out of the air in the first place: the envelope protection would have automatically kept it in level flight in spite of the drag of a stalled engine. But be that as it may, notes Waldrip, many pilots do like to feel that they can bend or break the airplane if they absolutely have to. Certainly that message has been received loud and clear at McDonnell Douglas. "Our strategy [on the MD-11] is that the pilot must have overriding authority," says Miller, "and he must be able to exercise that authority by the normal method"—the same eye-hand-brain control loop that a pilot develops through years of experience.

For example, imagine a pilot caught by wind shear, a sudden and very dangerous burst of cold air falling out of a rain cloud. The best thing to do in such a situation is to pull the nose up and put the power to the wall. Never mind if the engines have to be rebuilt later; you're just trying to keep from hitting the ground. However, this is hardly the time to be thinking about things like special override switches, says Miller. "You want your normal instinctive actions to always have the expected effects." So on an MD-11, the pilot would push the throttle all the way forward until it stopped to get the full rated power of the engine, with the built-in limits providing the same kind of security as the A320's envelope protection system. But then by doing the instinctive thing—pushing very, very hard—he could break through to a regime the A320 absolutely forbids: extreme thrust, well beyond the rated power. And so it goes throughout the MD-11, says Miller. The limits are there for safety, "but to override, you just have to pull hard or push hard."

The striking thing about Airbus' response to all this, however, is that the company starts from precisely the same position—"the pilot is always in command," says spokesman Paul Bond—and yet reaches such a different conclusion. Suppose that you are flying along, says Airbus' Guenzel, and you suddenly find yourself staring at a Cessna that has wandered into your airspace. So you swerve. Now, in a standard airliner, you would probably hold back from maneuvering as hard as you could for fear of tumbling out of control, or worse. "You would have to sneak up on it [2.5 G]," he says, "And when you got there you wouldn't be able to tell, because very few commercial pilots have ever flown 2.5 G." But in the A320, he says, you wouldn't have to hesitate: you could just slam the controller all the way to the side and instantly get out of there as fast as the plane will take you.

In short, goes the argument, envelope protection doesn't constrain the pilot. It liberates the pilot from uncertainty—and thus enhances safety. As Waldrip puts it, "it's reassuring to know that I can't pull back so hard that the wings fall off."

So—who's right?

Maybe everybody. It's a cliché to say that engineering is an art. But it is. And it's perfectly possible for Airbus, McDonnell Douglas, and all the rest to come up with very different solutions to the problem of aircraft automation, and still be perfectly correct. Indeed, as they look to the future, it may be less important that they come up with the "right" answers than that they keep asking the questions. To take just one example: manufacturers could easily build passenger airliners that are much more fuel-efficient than anything flying today—except that such airplanes would be inherently unstable in the air, and would instantly tumble out of control unless the on-board computers were able to compensate. The financial advantages are compelling. But are we really ready to put this kind of technology in a passenger jet—when we know that, even with the best engineering, both humans and machines will still make mistakes?

And yet, perhaps the most striking thing about the arguments over aircraft automation is the one thing that everyone seems to agree upon: "The automatics are just tools," says Waldrip. "But the pilot is still in charge. If we don't keep that, we're in trouble."

■ M. Mitchell Waldrop