FEATURE ARTICLE

COVER STORY

**Navigation systems guide planes ever more accurately, bringing efficiency and safety to the congested sky**

# Clear Skies Ahead

**By Elizabeth A. Bretz, Senior Associate Editor**

Several projects aimed squarely at upgrading airplane travel, either by enhancing navigation or by improving communications between pilots and air traffic controllers, drew closer to full implementation last year. In mid-June, the U.S. Federal Aviation Administration (FAA), Washington, D.C., outlined its 10-year Operational Evolution Plan to improve air travel by rolling out new technology to air traffic control facilities.

All the systemwide projects target congestion in the skies and on the runways. For too long a time, too many airports were scheduling too many takeoffs or landings for any given period, driving the numbers of delays up and into the news again and again. After 11 September, safer air travel became the burning issue. But congestion will no doubt return to prominence once airlines resume full schedules. Meantime, the global positioning system (GPS) satellite constellation and improved situational awareness tools are beginning to enhance safety now, and will alleviate congestion when it returns.

## The GPS difference

Two projects make heavy use of the GPS satellites' data: the wide-area and the local-area augmentation systems. With their aid, pilots will gain extremely precise information about where their own and nearby planes are, helping them to navigate better and increasing the accuracy of their instrument-based landings. The wide-area system is used for en route navigation and precision approaches for landing under Category I conditions (200-foot ceilings), while the local-area system supports aircraft operations in the terminal area, like taxiing, precision approach and landing, and taking off. Both achieve their precision through differential GPS, a technique that corrects a plain GPS signal to yield positioning accuracy within a meter.

Recall that the U.S. GPS constellation comprises 24 satellites circling the earth once every 12 sidereal hours at an altitude of 20 200 km. Four satellites define each of six orbital planes, which ensure signal capture from at least four satellites by receivers no matter where they are located--in this case, in the aircraft and ground stations. But the location information is somewhat in error because of propagation anomalies between each receiver and the transmitting satellites.

Currently, commercial GPS receivers deliver a positioning accuracy of about 20-30 meters. Inertial navigation systems on transoceanic aircraft, however, can be off course by several kilometers after several hours without an update. Aircraft flying over land do better. As they cross the sky, they navigate from one land-based radio signal to another and from VOR to VOR (VHF omnidirectional range localizer), but even this system lacks the accuracy of GPS-based navigation.

Still, by itself, GPS cannot provide accurate enough information for pilots to fly an exact course, especially when it comes to landing. (GPS does provide an "acceptable" course by FAA standards for an en route or oceanic flight path.) Even 10 meters can mean the difference between landing on the end of the runway or in a large body of water or a heavily residential neighborhood.

That's where the augmentation systems shine. The wide-area augmentation system (WAAS) uses a series of ground stations with known locations spread across the United States, plus a communications network, to determine the accuracy and integrity of the GPS signal data. (The European version is known as the satellite-based augmentation system, or SBAS.) Each ground station's location is compared with the location data transmitted by GPS, and any difference between them is calculated as the range error, or correction factor.

Using this factor, the wide-area system adjusts the GPS signal to produce a differential GPS location accurate to within a meter, which is broadcast via satellite to aircraft (and anyone else) having a WAAS-enabled receiver. The 25 WAAS ground stations in the United States are in place and operational, providing their signal around the clock to WAAS-equipped aircraft. The FAA's contractor on the project, Raytheon Command, Control, Communication and Information Systems, in Fullerton, Calif., is currently enhancing the software and expects commissioning of the system in 2003.

The FAA expects the WAAS network to expand to Canada, Iceland, Mexico, Panama, and other countries. Japan, Europe, and Australia are building systems compatible with existing WAAS avionics.

## Landing requires precise position data

The local-area augmentation system (LAAS), used for takeoff, landing, and taxiing, also supplies an extremely precise GPS correction. But as its name suggests, a LAAS ground station lacks the reach of WAAS; its VHF radio broadcasts reach no more than 37 km in any direction from the airport where it is located, Bruce Solomon, a program manager in air traffic management systems for Raytheon, told IEEE Spectrum.

Inside the plane, little equipment is needed beyond the GPS receivers already in most aircraft, said Solomon. Commercial planes built over the last few years possess multimode receivers that receive the GPS signal and estimate a position. By adding a LAAS datalink receiver to that mix, signals can be received from LAAS ground stations, too.

(Multimode receivers can handle several international standards such as U.S. and Russian GPS signals, VOR, and landing system signals. The European satellite navigation system known as Galileo is expected to be compatible with existing GPS. So multimode receivers will accommodate Galileo, too, when it is operational, perhaps as early as 2005.)

The only other element needed is algorithms to process the differential calculations sent by uplink to correct the raw GPS signal. "The algorithms must provide a precise estimate of where you are and give pilots a high degree of confidence in the integrity of the signal," if the system is going to do everything it is supposed to, said Solomon.

No contractor has yet been chosen for the local-area system by the FAA. But Raytheon, under an Air Force contract, is the contractor for the LAAS military counterpart known as the joint precision approach and landing system (JPALS). The FAA and the Department of Defense want the two systems to be compatible [see "Pieces of the Precision Landing Puzzle"]. Led by Raytheon, Honeywell, Rockwell-Collins, and FedEx Express, a handful of companies is working on ground stations and avionics for the two systems.

The Defense Department's JPALS is a landing system for ceilings of 100 feet down to zero feet that works in all weather, including zero visibility, without allowing its signal to be jammed or otherwise tampered with [see "Is Remote Control Next?"]. It is also compatible with similar civilian systems. On the other hand, LAAS, like WAAS, has no antijamming requirement, at least not yet. LAAS is expected to work in Category III conditions (50-0-foot ceilings), though planes likely would be grounded in a zero-visibility situation.

At present, the most prevalent technology for landing an aircraft in poor visibility requires an instrument landing system (ILS) transmitter at the end of each runway. To land, a plane descends along the ILS glide slope and localizer beams straight toward the transmitter. In contrast, a single LAAS ground station can handle planes on curved approaches and so can cover all the runways at an airport, a distinct economic advantage. "And that's a big plus in areas where noise abatement is a big issue or [where it's necessary to] keep planes from flying over a certain area for whatever reason," noted Solomon.

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## Points to Ponder

HARD LANDINGS Boeing Co. studies indicate that 51 percent of all major accidents involving Western-built airliners in the last decade occurred during final approach and landing.

GRIDLOCK 31 U.S. airports handle 70 percent of U.S. airline traffic.

## The virtual radar approach

Among the more promising situational awareness tools now available to pilots is Automatic Dependent Surveillance-Broadcast (ADS-B), a system developed by, among others, UPS Aviation Technologies, of Salem, Ore. A big plus of ADS-B is its ability to provide the same real-time information to pilots in cockpits and to controllers on the ground. For the first time, the two groups can both "see" the same data, since ADS-B gives pilots, too, a picture of where they are in relation to nearby aircraft, as long as those aircraft have ADS-B installed.

Using a satellite or a radio link, the ADS system in a plane digitally transmits GPS location information and other data to ground control facilities, where it is displayed on controllers' workstations. By adding broadcast ability to plain ADS to create ADS-B, it is possible to distribute that information more widely and for pilots of other aircraft to receive a situational display of nearby air traffic.

Think of ADS-B as a virtual radar. Radar works by bouncing radio waves off airborne targets and then "interpreting" the reflected signal. With ADS-B, individual targets can be displayed without being identified. Instead, each ADS-B-equipped aircraft uses a digital link to broadcast its precise position along with such other data as airspeed, altitude, and maneuvering status (turning, climbing, or descending). (Unlike transponders, the system does not give such flight "name" data as "United 732.") In effect, anyone with ADS-B equipment--ground controllers and aircraft with an ADS-B display--gains a much more accurate depiction of air traffic than radar can provide.

Unlike conventional radar, ADS-B works at low altitudes and on the ground, so that it can serve to monitor traffic on the taxiways and runways of an airport. And it is effective in remote areas or in mountainous terrain where there is limited or no radar coverage.

To improve upon ADS-B, the FAA has set up an initiative called Safe Flight 21, which links a plane's virtual radar data to a shifting map on a cockpit display. This enables pilots to see where they are in relation to other aircraft and to the ground. Terrain features like mountains can be stored in the system, and added to the display whenever poor visibility and/or difficult terrain warrants it.

Weather data can also be added to the mix. Transmitted to the plane in real time by satellites or ground stations, it gives pilots a picture of developing storm fronts in their flight path. When weather data, terrain, and location information of nearby aircraft are combined on one multifunction display, the system offers a significant advantage over weather-only displays.

As part of the Safe Flight 21 program, the FAA is putting its technology into effect in Alaska's many smaller commercial single- and twin-engine propeller aircraft. A driving factor is the state's spotty radar coverage, a result of its size and the undoubted expense of deploying radar statewide. Under this effort, called Project Capstone, the FAA is paying about $15 000 per plane to equip each with the Safe Flight 21 avionics. By the end of last November, installations were complete on more than 130 aircraft like Cessnas, which seat fewer than 10 people and are used as air taxis to remote areas.

Karl Braun, a pilot with 15 years of experience, was not looking forward to having the Project Capstone technology put into the Cessnas he flies for Larry's Flying Service of Fairbanks. "It distracts the pilot, tempting him to worship technology instead of flying an airplane," he told *Spectrum*. Now that the system has been installed for about a year, Braun finds it "a deceptively useful toy," since it creates "a perception of situational awareness." But, he noted, he still is distracted by the system, much as GPS displays can distract car drivers. Braun estimates that his views are shared by about one in three of the pilots using the system. The others fall into the extremes, being either completely in favor or completely opposed.

## Next for takeoff...

So what does all this technology really mean for the flying public? Giving pilots a better picture of where they are in relation to the ground and other aircraft, whether taxiing or flying, reduces the chances of collisions. Providing the situational awareness picture requires the proper navigation tools, like ADS-B, LAAS, and WAAS.

Communication tools also have a role in improving the air traffic system for passengers, controllers, and flight crews. New technology being tested in Europe and the United States will reduce routine voice contact between pilots and controllers, replacing it with a two-way datalink. This is part of an improved ground-based air traffic management system in development.

Combine the communication, navigation, and situational awareness tools with the authority to navigate airspace more freely and make precision landings, and the congestion experienced before 11 September is expected to largely dissipate. Less congestion in the air and on the tarmac translates into a safer, more pleasant flight for passengers and pilots alike.

ARTWORK: PETE MCARTHUR

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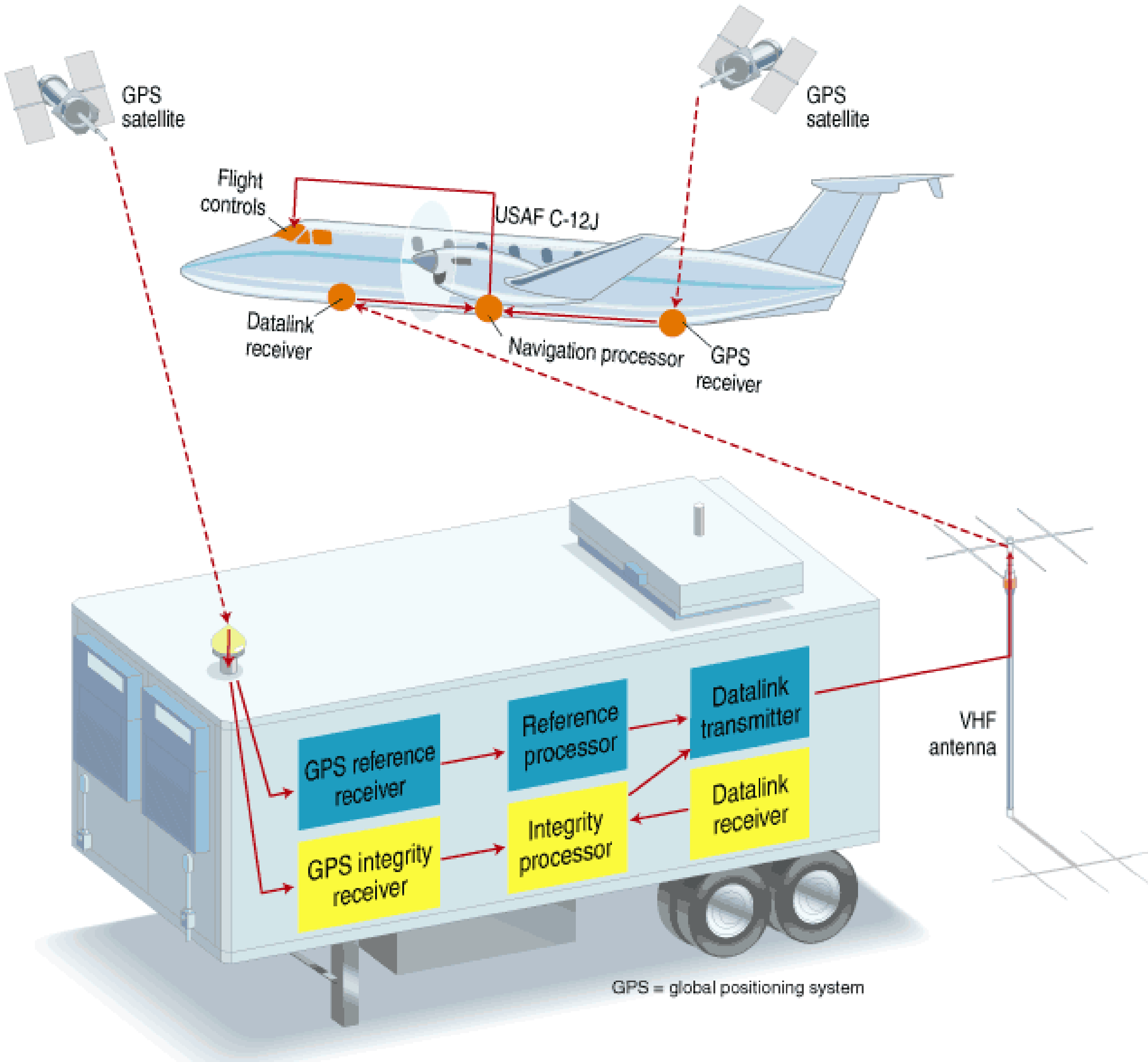
## Pieces of The Precision Landing Puzzle

In successful tests last October of the U.S. Defense Department's joint precision approach and landing system (JPALS), the differential GPS and ground-station equipment was housed in a trailer parked near the runways at Holloman Air Force Base, New Mexico.

An integrity receiver analyzes the quality of incoming signals (GPS and datalink) and estimates correction integrity. The ground-based datalink VHF transmits the GPS corrections, integrity estimates, and approach pattern (glidepath) waypoints to the plane's avionics.

The civilian local-area augmentation system (LAAS) works similarly.



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## Is Remote Control Next?

In early October, Raytheon Co., Lexington, Mass., was widely reported as having successfully landed a FedEx Express 727-200 cargo aircraft using remote control. The mainstream press, still full of news about the tragedies of 11 September, depicted this achievement as a way to prevent hijackings: someone on the ground could safely wrest control from cockpit intruders and land the plane.

It sounds great, but it isn't exactly what Raytheon, FedEx, and other test participants did, said Bruce Solomon, a Raytheon program manager in air traffic management systems. The plane was able to land under autopilot control, called an autoland, by using differential course corrections transmitted by the ground station. No one was flying the plane from a remote location. "We were really testing the interoperability of the civilian LAAS [local-area augmentation system] technology with the military JPALS [joint precision approach and landing system] ground station," Solomon told IEEE Spectrum.

The FedEx jet was equipped with a Rockwell-Collins LAAS receiver (the GNLU-930 multimode model). At Holloman Air Force Base, in New Mexico, a ground station developed for a three-month JPALS test fed differential corrections and desired flight path data via VHF uplink into the receiver for a precision approach. Similarly, a civilian LAAS prototype station at Salt Lake City International Airport guided a precision landing there by the FedEx plane.

The jet made 16 Category I approaches. That is, despite visual flight rules conditions in effect, the pilot was able to maintain Category I conditions: a 200-foot ceiling and 0.5-mile visibility. After pilot-flown approaches were done as a reference for the tests, six full autolands were done using the JPALS ground station at Holloman. "The consistency of the approaches allowed us to proceed to actual autolandings with very little delay," said Steve Kuhar, senior technical advisor in FedEx's flight department.

Autoland systems vary from plane to plane, but the concept is the same. The instrument landing system (ILS), or in the test scenario, the JPALS or LAAS, indicates in the cockpit the horizontal and vertical limits of the desired flight path for the landing approach. The aircraft is not receiving fresh data or being controlled remotely, Solomon explained. Rather, the on-board system is using the radio signal to correct the landing approach path. While the pilots monitor the approach, they rarely touch the controls until the aircraft has landed.

"It was a very successful test," Solomon said. As for the remote control using LAAS-type technology, "It's a promising technology for possibly achieving 'remote control'—if that's the term to use--but it will require a significant amount of sound engineering. Long before then, JPALS and LAAS will be out there [working]—hopefully in the next five years."

—E.A.B.