IN TRIBUTE

to the centennial celebration of the
Wright brothers’ flight, EDN looks at the state
of the art as well as future developments in electronics in aviation. We investigate how electronics has impacted navigation, engine control, and flight control. For fun, we update you on the latest in infotainment, as commercial airliners link with the ground via broadband channels bounced off satellites. Finally, we examine the way engineers are essentially embedding sensors in the fabric of the modern plane and how the aircraft itself may someday morph at different stages of flight. And, although predictions are always chancy, you never know—who would have thought we’d have come so far so fast?
For those of us in the electronics industry, it’s not news that electronics invades a predominantly mechanical device and quickly runs rampant.

Just look at how many microprocessors are in today’s cars. But electronics have been slow to pervade aircraft. Sure, radio-communication and navigation systems have for years been electronics-based, because both relied on RF-communications technologies. But many aircraft systems, even on modern airliners, whether gauges or flight controls, are mechanical or hydraulic, rather than electronic. Well, the electronics era is upon us. The newest avionics systems feature PC-like displays replacing both paper charts and mechanical gauges. The revolution is on in avionics, navigation, engine control, and flight control.

In the century since Orville and Wilbur Wright pioneered human flight, electronics technologies have taken a back seat in the advancement of aviation relative to mechanical and aerodynamic technologies. Granted, the development of jet engines and similar avionics technologies required electrical components. But many of the most common electronics currently in use are quite old. “The navigation systems that we use were developed just after the Wright Brothers flight,” says Boeing’s director of product marketing, Ken Hiebert. Hiebert is exaggerating a bit. As he points out, however, the widely used air- and ground-based navigation systems, such as VOR (VHF-omnidirectional-range) systems that airliners use date to just after World War II. Engineering on the older but still operational NDB (nondirectional-beacon) system began in the 1920s. The history of the ILS (instrument-landing system) that adds altitude guidance to the directional guidance of NDB and VOR starts in the 1940s. And ILS is the primary system in use today that allows planes to land with low visibility.

No one would suggest that electronics haven’t improved the functions of VOR systems, NDB systems, and ILSs. But in an age in which the GPS (global positioning system) is an everyday feature in our cars and in which our mili-
tary efforts couldn’t succeed without GPS, it’s probably time to move away from land-based navigation systems. And GPS is beginning to play a bigger role in aviation.

Don’t misunderstand. Private and commercial airline pilots alike have been using GPS to augment the other systems—but it’s only in the past year or so that the FAA (Federal Aviation Administration) has certified some GPS-based systems for mission-critical use. GPS can deliver benefits ranging from more efficient use of runways to improved fuel economy.

For instance, consider the RNP (Required Navigation Performance) scheme, which airway agencies worldwide are specifying. RNP pertains to the accuracy with which pilots and air controllers can ascertain a plane’s location. Older navigation systems work fairly well over land. But over the vast expanses of, say, the Pacific Ocean, where there are no VOR beacons, neither a pilot nor an air-traffic controller can know the precise location of a plane. So, the commercial-traffic “highways”—many miles wide and thousands of feet high—were inefficient. The wasted airspace means that fewer planes can operate at the higher altitudes in which jets are most fuel-efficient.

GPS enables RNP highways to be as small as six miles wide and 1000 ft high. The in-plane functions that allow RNP to work, RNAV (area navigation) works with RNP to offer a 30-times more efficient use of airspace over the Pacific, according to Hiebert.

SAFE LANDINGS

In flying, however, safe landings are the ultimate goal. And GPS can make landings safer and best ILS in performance and price in IFR (instrument-flight-rule) conditions with low visibility. Consider the GLS (GPS Landing System), which can allow an autopilot to land an airliner within 10-ft accuracy on a runway center line and within 100 ft of the target along the runway. Now, the FAA hasn’t certified GLS to allow such landings, but the goal of the system is to meet that footprint 99% of the time.

GLS uses a combination of GPS and land-based technologies. GPS offers 10m location accuracy, now that the government has removed the selective-availability limitations that previously reserved the precise 10m capability for military use. And 10m accuracy is fine for cruise missiles, but an airliner trying to touch down within 10 ft of the center line requires more precise position data. GLS instead uses a differential-correction scheme reminiscent of the selective-availability era that brings accuracy to 1m. GLS derives precise data via differential-correction information sent from an airfield-based LAAS (local-area augmentation system) to an MMR (multi-mode receiver) in the plane (Figure 1). In Boeing’s case, Rockwell Collins supplies the MMR, and the FAA this year certified it with a Honeywell LAAS.

The FAA initially certified the GLS for use in environments with go/no-go decision heights of 200 ft and half-mile visibility; in other words, runway visual range is 1800 ft. In the future, autoland- ing or operation with 700-ft visibility and 50-ft decision height may be possible.

But the GLS scheme does more than just allow safe landings in increasingly adverse conditions. It’s both cheaper than and makes more efficient use of runways than the ILS. ILS uses a separate ground-based system for each runway. A single slab of runway concrete actually comprises two runways in pilot or ILS parlance because you can land from either direction. A single LAAS costs approximately $500,000—about the same as an ILS—but can handle multiple runways.

Plus, GLS allows more frequent landings. Say you have a plane landing and a plane on final approach. In IFR conditions today, the FAA mandates an eight- to 10-mile separation. The fact that the landing plane blankets the ILS signal until that landing plane is off the active runway is in part the reason for the separation guidelines. GLS has no such problems and might support safe IFR landings with only three miles of separation. GLS won’t immediately replace ILS because airport agencies have funding issues and the ILS works. But new installations will be GLS-based, and six airports already have the technology. Moreover, the system will allow airfields in foreign countries that have no ILS to more economically support IFR operations.

Even without the LAAS, GPS technology is starting to usurp the need for ILS. The RNAV systems make IFR landings possible even without ILS on a field. Last summer, the FAA certified the Boeing Integrated Approach Navigation system, which uses an RNAV system to make constant-speed, constant-descent-rate IFR approaches to fields with no ILS. The plane must break the weather ceiling at 800 to 1000 ft, but Boeing believes the system is safe with 200-ft ceilings.

GLASS COCKPIT

“Electronics reduce the pilot workload and make it safer to fly,” states Don Burtis, vice president of avionics and electronics at Eclipse Aviation. Burtis’ statement is simple yet profound. In most major aviation accidents, you can hear...
pilots on the black-box recordings asking what is going wrong. And, although systems such as RNAV offer great data, the data is useless unless the pilot can easily interpret and digest the info, especially when things go wrong. So, avionics systems that display flight information in the cockpit are ripe for innovation.

Take a look at the cockpit of one of the newest airliner models, such as the Airbus 340 or Boeing 777, and you’ll see PC-like flat-panel displays. But, again, electronics has been slow to pervade the cockpit. Look in a workhorse 737 cockpit, and you’ll see traditional gauges and switches that are more impressive only in number than those in the typical Cessna. But the EFIS (electronic-flight-instrumentation system), or “glass cockpit,” is coming to commercial airliners (Figure 2).

Garmin, for instance, has developed the G1000 family of flight decks that target small planes, and Cessna will early next year begin to ship planes with the system. The so-called glass cockpit includes a 10-in. PFD (primary-flight display) that replaces such equipment as compasses, altimeters, climb indicators, air-speed indicators, and the artificial horizon that shows the planes attitude relative to straight and level flight. The system also includes a 10- or 15-in. MFD (multifunction display) that displays weather, navigation, and terrain info. Both the PFD and the MFD support 1028 × 764-pixel resolution and wide viewing angles, and users can read them in sunlight. Planes such as the Cessna 182 (Figure 3), which many private- aircraft pilots favor, may have a single PFD and a single MFD. More complex aircraft may have a PFD for both front seats and an MFD mounted between the two.

Eclipse Aviation will also use the EFIS concept for the integrated avionics package that it is developing for the Eclipse 500 six-seat business jet. Eclipse calls its system Avio, and Avidyne will build much of it. Avidyne supplies integrated flight decks for a number of executive planes and jets.

Certification for the Eclipse 500 is still three years off. But Eclipse has presold more than 2000 of the jets due to its ability to get the price of a six-seat jet with more than 1200-mile range to less than $1 million. Electronics will in large part make this price possible.

Eclipse’s Burtis points out what “integrated” means in Avio (Figure 4). The system displays the typical gauge-replacement, weather, and navigation info. But the system ties into every aspect of the airplane design. For instance, the jet will use FADEC (full-authority digital-engine controller) technology. In the case of the Eclipse 500, the plane has dual redundant PowerPC-based FADECs for each engine.

The Eclipse engineers programmed the Avio computer with all the characteristics of proper engine operation and with how those characteristics change with factors such as altitude and temperature. The system monitors, for example, fuel flow and engine temperature and can automatically spot instances in which the engines may be working harder than they should. The system makes for safer flying, better reliability, and lower maintenance cost. The integrated approach also allows the Eclipse 500 to have automatic throttle control in the autopilot system. Although some single-engine, two-seat Cessna 152s may have autopilots, such autopilots handle the control surfaces but not the throttle. Autothrottle is not normally available in planes that cost less than $20 million.

Eclipse has leveraged numerous other electronics technologies in the Eclipse 500. For instance, the jet will use a permanent-magnet-based combination generator/starter—an innovation you should soon see in cars. Elimination of the brushes that you find in most motors means less maintenance. The jet has 30 onboard computers and many more microprocessors that allow the Avio system to monitor every circuit breaker/switch. The communication and navigation systems use direct-conversion RF technology and software-defined radios. The company is leveraging the cost benefits of technologies developed for consumer systems, such as cellular telephony and 802.11 or WiFi wireless LANs. Eclipse officials believe that the economical aspects of its jet will allow travelers the choice of a private flight for the same cost as an unrestricted airline ticket.

THE E PLANE

Boeing has perhaps led the way in integrated avionics. The 777 is probably the most integrated plane flying, and the upcoming 7E7 will take the technology to another level. But Boeing has delivered innovative avionics systems up and down the company’s product line that acknowledge that the pilot is ultimately the key to safety.

Consider HUDs (“head-up” displays). Both BAE Systems and Rockwell Collins supply HUDs to
Boeing. The systems allow the pilot to look out the window while continuing to monitor key data on a transparent glass display. The systems are popular on the 737 and many other jet models.

Head-up versus head-down flying is a contentious subject. Some aerospace experts believe that a pilot should look down at the array of displays and indicators that fill a flight deck. Boeing’s Hiebert, however, states, “Flight-deck philosophy must address the pilot as the most important computer.” HUDs, according to Hiebert support “full-spectrum flying,” giving the pilot all of the information he or she needs to manually fly the plane.

Hiebert claims that the HUD system gives the pilot 2.5 sec more to react to a situation. For instance, consider a pilot on a final approach in bad weather. When the plane breaks through the weather ceiling, the pilot should be able to see the runway. The pilot must either acknowledge sight of the runway or abort the landing. If the pilot is flying head down when the plane breaks the ceiling, it takes 2.5 sec to look up and focus on the new context. With an HUD, the pilot is already focused on finding the runway while still monitoring the instruments.

And HUDs are useful in situations other than landing. The HUD can display collision-avoidance information, including instructions on climbing, descending, or turning to avoid an accident.

Boeing also continues to add features to its head-down displays that provide the pilot with critical data in real time. For instance, many planes have a situational-awareness display that shows potential ground obstacles. But most such displays use the “God’s eye view.” The Boeing VSD (vertical-situation-display) system adds profile information to precisely identify the height of any terrain within a mile of the plane. The system can automatically set climb and power vectors to avoid terrain.

In fact, what’s coming is so-called synthetic vision. (Figure 4) In 4 Gbytes of storage space, avionics-system designers can now store every building, mountain, tree, and any other terrain feature in the world. Next-generation avionics will include a display that synthetically renders the outside world for the pilot, even if weather prevents the pilot from seeing out the window.

Other technologies, such as infrared sensors, will essentially allow pilots to see through bad weather and identify runways and other objects. Some business jets already use the technology, but the FAA has not yet certified the systems for commercial airliners.

VIRTUAL PAPER

So, electronics make pilots’ lives simpler and all of our travel safer during flight, but what has our industry done for the pilots’ backs? You see these guys wandering through airports not only pulling rolling suitcases, but also toting flight bags stuffed with 50 lbs of books and papers. And all of you techies know that your PDAs could store all of that info. Welcome to the era of the EFB (electronic flight bag).

Today, pilots handle a lot of paper. They carry the in-route maps that Jeppesen and other sources provide. They carry reams of approach plates, which Jeppesen also distributes. The approach plates provide the intricate details that pilots use to make IFR approaches to airports. To make matters worse, Jeppesen constantly distributes updates of these approach plates. Pilots also carry checklists, emergency manuals, and other critical info. And all of you techies know that your PDAs could store all of that info. Welcome to the era of the EFB (electronic flight bag).

Astronautics was among the first companies to build a custom-EFB prototype, based on a single Intel processor and Windows operating system. But the FAA is rightfully strict on what type of hardware and software vendors can employ in various instances. Avionics systems that provide critical information, such as altitude in flight, must meet “Level A” requirements, meaning essentially that the system can never fail. The EFB does not handle tasks that require Level A reliability. Some of the features of an EFB, such as electronic logbooks and flight manuals, don’t require super reliability. The FAA allows use of Level E systems, which can essentially be tablet or notebook PCs, to host those systems.
that don’t require super reliability. Other functions ripe for EFB implementation fall between these two extremes. For instance, the Astronautics EFB can read GPS data from the onboard avionics systems and provide “ownership” position of the plane on the tarmac. The FAA mandates that such an application in use during taxi operations meet “Level C” requirements, meaning that the system never delivers false information.

To meet the Level C requirement, Astronautics partitioned its production EFB design among two processors and two operating systems (Figure 5). Some anti-Microsoft cynics in the crowd will rejoice in the fact that the Linux portion of the system handles the Level C requirements, whereas the Windows 2000 embedded portion handles Level E luxuries, such as weight and balance calculations and databases. So why use Windows at all? Astronautics marketing manager Bill Ruhl states, “There was just so much available for Windows.” For instance, Jeppesen offers the JepView Flight Deck program for Windows that the company originally developed for pre-flight planning but that EFB initiatives are now employing. The program works with the electronic version of the Jeppesen approach plates and in-route maps.

For those who are wondering, Astronautics didn’t reject Windows for the Level C portion specifically due to reliability concerns. According to Bill Barnes, senior software engineer at BAE Systems, for a system to meet Level C requirements, engineers must scour the source code and statically map every aspect of the code to prevent such occurrences as memory leakage. Whether you could accomplish that goal with Windows is technically speaking debatable but logistically impossible with Microsoft’s iron fist of control.

The FAA has certified three classes of EFB. A Class 1 EFB is essentially a tablet or a notebook PC that has no interface to the avionics systems. And just as you must stow your portable devices during takeoff and landing, the FAA mandates that you cannot use Class 1 EFBs at altitudes lower than 10,000 ft, because flying PCs can be dangerous.

Class 2 EFBs can still use PC-industry technology but must be permanently mounted to the aircraft and may have limited interface to avionics systems. Astronautics developed a Class 3 EFB that is installed equipment and fully connected to the avionics systems. And Boeing has certified the Astronautics EFB running Jeppesen software for use on the 777. KLM is the first airline to fly the system, which features an airport moving map displaying the plane position on the tarmac, a performance calculator for ideal speeds and engine settings, and a cabin video-surveillance system for security.

The Astronautics EFB’s redundant design provides separate systems for the pilot and co-pilot. Although each can see the other’s display, the computers are separated for safety. And both have Linux and Windows systems that each have dedicated 40-Gbyte disk drives and that are based on 650-MHz Intel CPUs.

Techie private pilots are ahead of the curve and have for some time been cobbling together their own EFBs, just as they overclock their PCs at night. For example, you can buy an electronic subscription from Jeppesen for little more than $200 a year that covers the Southwest and includes all approach plates, which the company updates every two weeks. But commercially accepted EFB technology will quickly become widespread. It may be a few years before commercial aviation can go paperless. Jeppesen public-relations specialist Eric Anderson states, however, “Some business jets are paperless today. They operate on two tablet PCs.”

Boeing’s EFB is decidedly low-tech from a connectivity perspective. In Boeing’s future scheme, however, all of the data for the EFB will flow automatically to the system via the CoreNet box, which the company is developing with Rockwell Collins as the data center of the plane. The link may be via Ethernet at the gate, but Boeing has demonstrated WiFi connections to all planes on the Terminal 2 tarmac at Singapore’s Changi airport. Down the road, Boeing’s Connexion system may upload the latest Jeppesen approach plates in flight (Reference 1).

References
1. Dipert, Brian, “Fly with the Internet, at your seat,” this issue, pg 41.