Photo by Jack Sykes

Coloring inside—and outside—the box

Cockpit evolution and the long flight from an aural to a visual world

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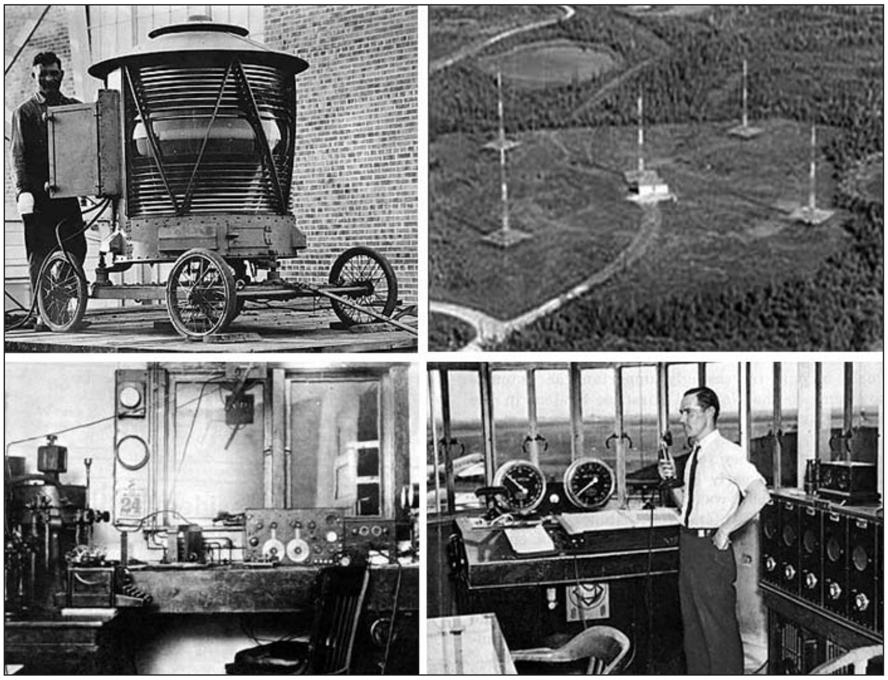
Bombardier Global 5000 on final approach to GVA (Geneva, Switzerland). EFIS displays promote aircraft safety through increased pilot situational awareness.

We have come a long way. In the early days, the cockpit was nothing more than a seat and a stick. The only way to get around was to look outside the airplane, through a window if you were lucky to have one, and follow roads, railroad tracks and farm fields. Over the years the flightdeck has evolved from the bare essentials to a vibrant office in which to manage many colorful systems.

In the beginning years, looking outside to navigate was great during the day, but nearly impossible at night. In 1919, that all changed when US Army Air Service Lieut Donald Bruner used bonfires that were lit by post office staff, farmers and the public, as the first artificial beacons to navigate at night. This continued until 1923, when the first lighted airway was created from McCook Field in Dayton OH to Norton Field in Columbus OH—an amazing 72 miles. By 1933, the Aeronautics Branch of the Dept of Commerce had built 18,000 miles of airway using 15,000 beacons. Each beacon could be seen 40 miles away on a clear night.

Every tower was identified by painted numbers for daytime identification and flashed a certain sequence and color for night-time identification, corresponding to the map that pilots carried. In addition to rotating beacons, fixed lights were placed on the towers pointing to the previous tower and the next tower, in effect creating an aerial roadmap. The last airway light beacon was officially shut down in 1973, although the state of Montana still operates 19 working light beacon towers in its rugged western mountainous terrain.

As the Postal Service began focusing on safety and reliability, in 1940 it established minimum light requirements for airmail stations. This was the first attempt to assist pilots landing using artificial guidance. A 500-watt revolving searchlight projected a beam parallel to the ground, while another beam projected into the wind indicated the proper approach. Later, lights were used to project rows that created a funnel that allowed the pilot to fly through to locate the end of the runway.



Photos courtesy FAA

(L–R top to bottom) Early 500-million-candlepower landing field floodlight. Introduced in 1928, the first practical radio navigation aid was the low-frequency 4-course radio range. Salt Lake City UT air mail radio station, Mar 1925. Controller Bill Darby demonstrates the latest equipment in Newark NJ tower—the year is 1936.

Until 1926 there was no 2-way radio communication between pilots and ground stations. Pilots were unable to receive information related to other airplanes in the air or about changes in weather conditions. In College Park MD, the Bureau of Standards created an experimental ground-to-air radio telephone that could communicate up to 50 miles. Soon after, a transmitter was placed at Bellefonte PA on a transcontinental airway, which made a successful transmission to an airmail airplane 150 miles away. The first radio-equipped airport control tower was built in Cleveland OH in 1930. It had a range of 15 miles. The controller would clear an aircraft for takeoff or landing, but the pilot could still decide on the best path for himself. Interestingly enough, those days may come again.

The Aeronautics Branch continued to add radio stations. By 1934, pilots were using 2-way radio communication to request navigation assistance. Collins Radio Company, founded by Arthur Collins in Cedar Rapids IA, began designing and producing short-wave radio equipment and was instrumental in furthering 2-way radio communication in the aerospace industry.

Early nav enhancements

As radio communication technology was moving forward, so was aircraft navigation. The first standardized 4-course radio range was installed in 1929. Pilots listened to Morse code audio signals to determine whether they were on course. Four towers set in a square transmitted the letters A and N in Morse code. A pilot flying along any of the 4 beams toward the square would hear only an A or an N, and the dashes and dots would grow louder or fainter as he flew, depending on whether he was flying toward or away from one of the corners. The beams flared out and, at certain points, overlapped. Where the A or N signals meshed, the Morse code dashes and dots sounded a steady hum, painting an audio roadway for the pilot, often called "on the beam." However, there was no cockpit indication that corresponded to the Morse code—navigation was conducted through aural tones only—and this technology remained as the standard of civil air navigation through World War II.

One of the first helpful visual navigation instruments to be introduced was the radio compass, which pointed to a beacon and was used as a homing device.

All flying was done in VFR conditions until Sep 1929, when Army Lt James Doolittle became the first pilot to takeoff, fly a set course and land using only instrument guidance. He used the 4-course radio range—"flying the beam"—and radio marker beacons for course guidance and distance to the runway. Doolittle augmented his navigation capability by using flight instruments, including a directional gyroscope with an artificial horizon developed by Lawrence Sperry and his Gyroscope Company and the first barometric altimeter created by Paul Kollsman. This was the beginning of Kollsman Inc and the "Kollsman window" of today.

The first instrument landing by a system incorporating a glidepath was made at College Park MD. The glidepath was achieved by aligning an inclined radio beam with the runway, providing a path approximating the gliding angle of an airplane, culminating with the first landing of a scheduled US passenger airliner using an ILS on Jan 26, 1938 in Pittsburgh PA. Through today, the basic ILS has remained unchanged, the pilot viewing lateral and vertical course guidance from the instrument in the cockpit and listening to and observing visually the nondirectional radio marker beacons to determine distance from the runway.

By 1941, the 4-course radio range had been supplemented with an ultrahigh-frequency radio range system for long-range navigation, still using audio for course guidance. World War II triggered great ad-

In 1928, Paul Kollsman changed aviation by inventing the world's first accurate barometric altimeter with its "Kollsman window."

vances in communication and navigation systems, one of the greatest occurring in 1944 when the static-free VHF omnidirectional radio range (VOR) was introduced. For the first time, pilots were able to navigate by looking at a dial on their instrument panel and could identify distinctly whether they were on course without listening to a radio signal. In 1947, the Civil Aeronautics Administration (CAA) commissioned its first VOR.

In May 1946, CAA gave an initial demonstration of the first radar-equipped control tower for civilian flying atop the agency's experimental station at Indianapolis Municipal Airport. Raytheon had built the basic radar equipment for the Navy. Initially, radar was used for detection and aircraft separation rather than guidance—then, in 1947, ground-controlled approach (GCA) went into service. Using precision approach radar (PAR) for precision approaches or airport surveillance radar (ASR) for nonprecision approaches, the controller would guide the pilot to the runway with voice commands such as "Fly left," "Fly down," "Approaching course" and "Two miles from touchdown."

Until this point, the flightdeck had been equipped with a modest set of tools—the basic 6 flight instruments, 2-way radio communication and adequate navigation instruments, including VOR, ADF and ILS, and a good mix of aural and visual tools—to remain safe. Over the following 20 years or so, most of the advances in avionics and infrastructure focused on making equipment lighter, faster and more reliable.

Sputnik and the birth of GPS

The realization of opportunities that the global positioning system (GPS)—a satellite-based system for navigation—could create was prompted by the launch of the Soviet *Sputnik* in 1957. GPS was operated solely by the US Dept of Defense and used by the military until 1983, at which time President Ronald Reagan declared that GPS would be available to the civilian community. It was made available during the early 1990s as steps were taken to shore up availability, reliability and technical standards.

In the interim, RNAV was developed by the early 1970s. This allowed pilots to fly off-airway routes, using the pre-existing course deviation indicator (CDI) from the VOR instrument and, later, the horizontal situation indicator (HSI).

Not until the early to mid-1980s did pilots truly see a different cockpit. Major innovations during this decade transformed the flightdeck into a systems environment that used visual displays as the medium for situational awareness and a higher degree of aircraft command. The impetus for change was the availability of relatively inexpensive high-speed computing power and digital technology, including digital data busses.

Universal Avionics Vision 1 SVS Egocentric 3D was approved by FAA in Nov 2005. Imagery depicts terrain in real time for direction of flight, including pitch and roll, while the system retains standard foreground symbology and traditional flight director cues.

Photo by Jack Sykes

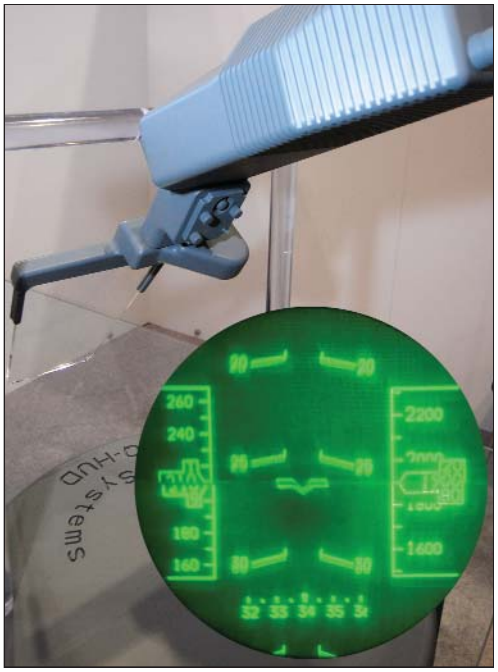
The flight management system (FMS) for business aircraft was pioneered in the 1970s by Sperry Flight Systems (now part of Honeywell), but FMSs did not see widespread use until the mid-1980s. Early variants, such as the Universal Avionics UNS1, built in 1982, included a 3-inch monochrome screen (color was not introduced until 1986), multi navigation sensors and a navigation database. Pilots could enter a waypoint, fly direct, and view limited navigation performance on the monochrome display. In addition, the FMS could drive navigation instruments such as the HSI. Today, FMS capability has grown to include autotuning navigation aids, uploading flightplans, determining top of descent, creating vertical and lateral navigation paths, and computing performance speeds for all phases of flight.

Research on the cathode ray tube (CRT) began with British Aircraft Corp (later part of BAe) in the 1970s at Weybridge in England. CRTs were introduced with a monochrome display. Color came later, once its reliability had been demonstrated.

In 1981, a BAC 1-11 airliner was outfitted with the first CRT primary flight display (PFD) and navigation display (ND) as a test bed for further development and demonstration. Early commercial versions replaced the mechanical ADI and HSI—renamed EADI and EHSI—and included features displaying waypoints along the planned route of flight, distance and time-to-go.

Subsequent versions of CRT displays combined all flight instruments into just 2 screens per pilot, and the entire instrument panel com-

VOR at ORL (Exec, Orlando FL). The VOR has not changed in appearance since its inception in the early 1940s.



BAE Quantum-HUD (Q-HUD) technology. EVS images are injected directly into the side of the combiner as holograms, rather than projected onto the HUD screen. Q-HUD will also provide a 15-fold increase in the size of the pilot "head motion box."

Sagem Avionics integrated cockpit display system (ICDS) upgrade in a Turbo Commander 690 with 10-in color AMLCD panels. Sagem ICDS provides primary flight instruments, engine instruments, moving maps, CAS advisories, terrain obstacle proximity system and warning/caution system. ICDS also integrates with radars and a traffic advisory system.

Photos courtesy Sagem Avionics

prised 4–6 CRTs. The abundance of information displayed was unprecedented. With a cursory look at the display screens, a pilot could see wind direction and speed, flap and landing gear retraction and extension speeds right on the airspeed indicator, dynamic stall speed warnings, weather radar superimposed on the navigation display, HSI, RMI and ADF needles displayed at once on the same screen.

TCAS, ACARS and HUDs

TCAS implementation started in late 1980 and afforded pilots visual information about imposing traffic through colored symbols and visual guidance used for climbing and descending escape maneuvers. A supplemental computer generated voice (non-ATC) commands provide warnings and escape maneuvers. In 1981, FAA adopted the traffic alert and collision avoidance system (TCAS) and contracted with Bendix Corp to provide TCAS II prototypes.

At the same time TCAS was coming onto the scene, airborne windshear alert systems and ground proximity warning systems (GPWS) were in development. Aural and visual guidance was delivered to the flightcrew with amber or red lights illuminating in the flightdeck and a voice repeating, "Windshear, windshear" or "Terrain, terrain," as appropriate.

Aircraft communications addressing and reporting system (ACARS) is a digital datalink system for transmission of messages between aircraft and ground stations via VHF and HF ground-based radio system or by satellite. ACARS was deployed in 1978 and became available for business aircraft in the late 1980s. It was further augmented in the early 1990s with satellite communication to supplement ARINC's voice communication network.

With ACARS, flightcrews could for the first time receive pertinent information via datalink without using voice communication with ATC. By 1991, pilots were able to receive ATC predeparture clearances (PDC) from the first 29 designated PDC airports. And when digital automatic terminal information service (D-ATIS) became available, crews could receive ATIS without listening to the recorded message on the VHF frequency. Text messages are read right from the ACARS display unit or integrated FMS display unit.

Now ACARS is used to upload flightplans right to the FMS, request and accept oceanic clearances, transmit on and off times, and transmit position reporting to ATC. To extend this thought, communications with ATC without voice is being used in limited but growing capacity through controller-pilot datalink communications (CPDLC).

Head-up displays (HUDs) have been around since the 1960s in military use, but the late 1990s saw their popularity growing in the civilian sector. Their benefits include reductions in controlled flight into terrain (CFIT) and runway incursions in low visibility. The HUD system portrays PFD information, localizer and glideslope data and a flight path vector (FPV) in the pilot's sightline by using a reflective combiner lens so that the symbols appear to the pilot to be superimposed on the outside world.

Kollsman combines a HUD with an enhanced vision system (EVS) using a forward-looking infrared (FLIR) camera—a set-up that allows pilots to continue looking forward with their heads up looking at the runway environment and surrounding terrain. The camera looks through haze and fog, day or night, enhancing pilot vision during low-visibility approaches and during taxiing.

During the 1990s faster microprocessing power and larger databases, coupled with 2 key initiatives, paved the way for what is in the cockpit today. These initiatives included the Clinton administration's announcement of a Presidential directive ensuring the availability of GPS signals to civilian users and research and development in liquid crystal displays (LCDs).

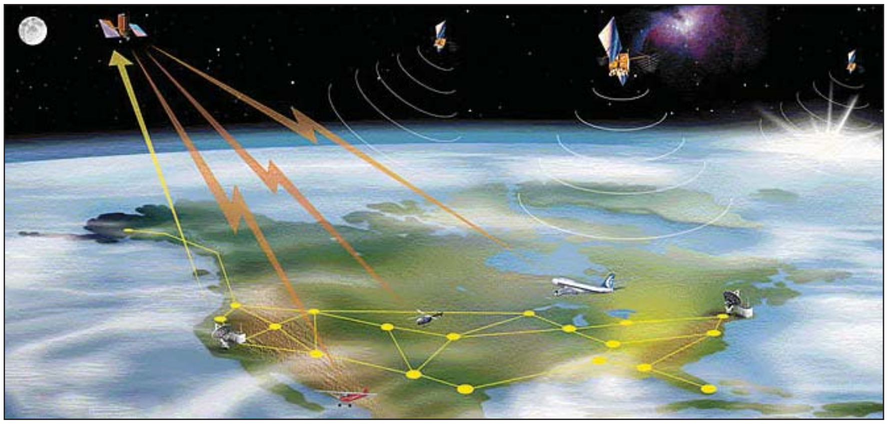


Photo courtesy FAA

A fully functional WAAS system requires geostationary satellites, ground reference stations and an airborne WAAS receiver and antenna.

\Photo courtesy Sandel

Sandel's new SA4550 primary attitude display upgrades electromechanical ADIs to a solid-state design, easy-to-read, LED-backlit, and pilot configurable display.

ADS-B and WAAS

GPS availability paved the way for automatic dependent surveillance–broadcast (ADS-B) and localizer performance with vertical guidance (LPV) approaches, both of which require a high degree of aircraft position accuracy from a satellite-based system, but neither of which could live up to their full potential without wide area augmentation system (WAAS) availability.

WAAS updates GPS position error and allows GPS to be the sole and primary tool for navigation. A limiting factor in commencing LPV approaches is that current fleets have not been upgraded with WAAS capable GPSs and FMSs. WAAS avionics is a relatively new phenomenon—both Rockwell Collins and Universal Avionics began delivering WAAS compatible avionics in 2007.

LCDs overcame the drawbacks of CRTs. The newer active matrix LCDs are not only lighter—they need less instrument depth and require less power, pixel sizes are fixed at all brightnesses, and they have perfect color tracking.

Integrating SVS

LCDs also led to development of the synthetic vision system (SVS). With SVS and LCD multifunction flight displays (MFDs), situational awareness and organization of information under pilot control is phenomenal. Gone are the blue and brown ADIs and 2D flight displays—they are replaced by a continuously updated, synthetically derived 3D view of the outside world, including graphics of mountains, lakes, airports, runway numbers and runway centerlines. The flight displays are capable of uploading weather graphics, weather reports and forecasts, and displaying surrounding aircraft traffic for added situational awareness.

Rockwell's Pro Line Fusion is an example of the latest in integrated avionics suites. Giving pilots greater flexibility and control over their instrumentation, it includes graphical flight planning and allows pilots to manage their flight displays through pilot-selectable information windows. The FMS CDU is now located in the MFD window, reducing 80 pages of typical FMS data to just 11.

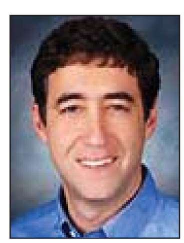
In 2002, Universal Avionics Vision 1 EXO became the first SVS certified for Part 25 aircraft. EXO gives the view from the pilot's seat, looking forward. Vision 1 EGO SVS, developed in 2005, gives the view from above and behind the aircraft, overlooking the right wing.

Garmin's G1000, certified for TAWS-equipped Part 23 aircraft, will see the 3D terrain change color to warn pilots of impending terrain hazards. It also includes highway in the sky (HITS) depiction to give the pilot immediate feedback of current position relative to planned position.

Without a doubt, the flightdeck will continue to evolve. Rockwell Collins Senior Dir, Business and Regional Systems Marketing Tim Rayl reports that "innovation continues using a team approach, with customers, OEMs and internally." Meanwhile, Universal Avionics Systems COO Paul De Herrera predicts "more realism in SVS as computing power and database storage capacity keep increasing."

Photo courtesy Cessna

Garmin's SVT brings new levels of situational awareness to the Cessna Citation Mustang cockpit by displaying the aircraft's position on an enhanced topographical database, including SafeTaxi, which gives a graphical representation of the aircraft in the airport environment.



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