FLIGHT SAFETY FOUNDATION
Airport Operations
Vol. 22 No. 2 For Everyone Concerned with the Safety of Flight March–April 1996

Radar Technology, Satellite Systems at Forefront of Global Effort to Reduce Runway Incursions

With worldwide aircraft movements predicted to increase steadily and airport congestion worsening, runway incursion prevention has become a top priority for the U.S. Federal Aviation Administration (FAA) and other national civil aviation regulatory agencies.

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The risk of runway incursions remains significant as aircraft movements increase worldwide and some airports permit low-visibility operations down to 300 feet (92 meters) runway visual range (RVR).

The U.S. Federal Aviation Administration (FAA) first launched a campaign to reduce runway incursions in 1991.

A 1992 survey of experienced airline pilots revealed that pilots had many concerns about problems with surface navigation at airports that could lead to runway incursions. The pilots cited confusing signs, marking and lighting of runways and taxiways; difficult-to-read airport charts; air traffic control (ATC) taxi instructions delivered at inconvenient, high-workload times such as landing and rollout; nonstandardized pilot terminology for radio communications concerning ground operations; radio frequency congestion; and other factors.[1]

In 1995, the FAA announced a new initiative, the Runway Incursion Action Plan. The plan involves five areas:

- Human performance, including reduction of human error, improved situational awareness and increased understanding of procedures and recommended practices for safe airport operation;
- Communications, including reduced frequency congestion and nonstandard phraseology, and improvement of crew coordination;
- Guidance, including provision of visual aids for pilots and vehicle operators in navigating airport surfaces;
- Surveillance, including deployment of ground movement radar and development of technology to transition to satellite-based automatic dependent surveillance, and safety systems for conflict-alert capability on airport surfaces; and,
- Surface traffic management, including development of automation and procedures to improve surface-movement efficiency and capacity in any weather. Automation is necessary to minimize controller workload and human error, which are responsible for most runway incursion incidents.

The plan is linked closely with U.S. Secretary of Transportation Federico Peña's "zero accidents" initiative, challenging the aerospace community to end all accidents in the air and on the ground. A significant decline in runway incursions followed the 1991 FAA runway incursion plan, but that improvement is not expected to continue without technology to provide automation and surface-movement conflict alerts, according to the FAA. "The Runway Incursion Action Plan is based on a proactive, focused partnership with airports, controllers and the entire aviation community to achieve the common goal of increased safety," FAA Administrator David R. Hinson said when the program was initiated.

The FAA defines a runway incursion as "any occurrence at an airport involving an aircraft, vehicle, person or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing or intending to land."

According to that definition, an aircraft or vehicle entering a runway without clearance is not a runway incursion unless a loss of separation ensues. "Runway incursions represent indicators of system safety, similar to near–midair collisions," the Runway Incursion Action Plan notes.

The FAA, the International Civil Aviation Organization (ICAO), Eurocontrol and several original equipment manufacturers are developing operational guidelines, hardware and software to address the concern.

The U.S. National Transportation Safety Board (NTSB) in 1990 placed reduction of runway incursions on the list of "Most Wanted" Transportation Safety Improvements, and the issue continues to appear on the list.

Efforts are focused primarily on two means of monitoring surface movements: Ground radar and satellite-based systems. Both technologies are based on automated systems that act without controller intervention and help counteract some aspects of human error.

Much of the technology being developed by the FAA is also being studied by European aviation agencies. For example, the Aerodrome Operations Planning Group of the European Air Navigation Planning Group, part of the European region of ICAO, is developing functional performance criteria for advanced surface movement, guidance and control.

In addition, ICAO's All Weather Operations Panel Working Group for Advanced Surface Movement Guidance and Control Systems is assessing the feasibility of using the global navigation satellite system (GNSS) to guide ground movement in a one-sensor-type solution that can support a variety of navigational functions in the air and on the ground.

In a parallel, coordinated effort, the U.S. Radio Technical Commission for Aeronautics (RTCA) Special Committee 159 is developing aviation system performance standards for airport surface navigation and surveillance using GNSS.

At most airports, runway and taxiway guidance is signage, "follow-me" vehicles, paper charts and verbal instructions given by the tower controller.

Surveillance information for the airport environment is currently provided by a number of independent radar systems, including airport surveillance radar (ASR), secondary surveillance radar (SSR), precision parallel runway monitor radar and airport surface detection equipment (ASDE) radar. "ASDE-3 is an advanced digital radar that penetrates rain, snow and fog to show controllers in the tower a picture of all airplanes and vehicles moving on runways and taxiways," the FAA said.

Incursions typically occur in three situations: Arrival on occupied runways, converging landings on intersecting runways or multiple departures too closely spaced on the same runway. The cause is usually a breakdown of communications, an error in surface navigation, a misunderstood clearance, a lack of situational awareness or some combination of those factors. Those errors can be classified as pilot deviations, operational errors in the air traffic control (ATC) system, and vehicle or pedestrian deviations (Figure 1, page 3).

Pilot deviations on the airport surface are defined as actions by a pilot that violate the U.S. Federal Aviation Regulations (FARs). ATC operational errors are "occurrences attributable to an element of the air traffic system which results in less than the applicable separation minima between two or more aircraft, or between an aircraft and terrain or obstacles ... ." Vehicle or pedestrian deviations occur when a vehicle operator, nonpilot operator of an aircraft or pedestrian enters the runway without ATC authorization. More incursions usually happen in spring and summer, when aviation activity and construction at airports are at their peaks.

The 1991 FAA runway incursion plan was prompted by a record number of incursions (281) in 1990.

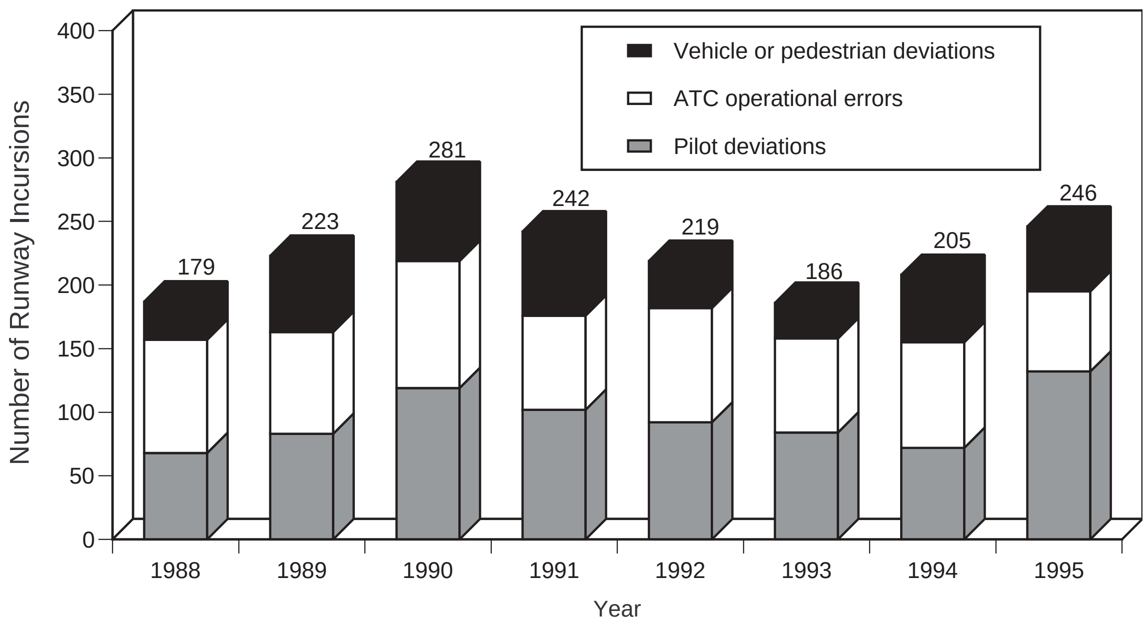
The 1991 FAA runway incursion plan was prompted by a record number of incursions (281) in 1990. The original plan reduced incursions by improvement in markings, signs, lighting and vehicle operator training. New procedures for low-visibility operations, such as prohibiting intersection departures on runways used for both takeoffs and landings at night and in inclement weather, also contributed to reduced incursions.

Runway incursion rates are calculated by dividing the number of runway incursions by the number of operations (takeoffs and landings). Rates are expressed as the number of runway incursions per 100,000 operations. The 1995 runway incursion rate was 0.38, up from 0.33 the previous year (Figure 2, page 4). (The increase was because of increases in vehicle deviations and controller errors.)

As a result of the 1991 effort, the FAA:

- Adopted new standards for airport signs and markings;
- Incorporated new controller memory enhancements and improved techniques for airport scanning;
- Made significant improvements in standardization of airport procedures;

U.S. Runway Incursions at Towered Airports Reported to FAA, by Type, 1988–1995



ATC = Air Traffic Control

FAA = U.S. Federal Aviation Administration

Source: U.S. Federal Aviation Administration National Aviation Safety Data Center

Figure 1

- Developed and implemented major technological advancements in airport surface movements;

- Undertook a comprehensive education and communications program with pilots, controllers, airport operators and other sectors of the aviation community to increase understanding and set the groundwork for continued reductions in runway incursions; and,

- Established a Runway Incursion Action Team that reviews movement operations at 50 high-priority airports.

Air traffic controllers are responsible for maintaining separation between aircraft on the runway and preventing collisions on taxiways. Pilots are responsible to see, and avoid collision with, other aircraft and vehicles. Vehicle operators are expected to yield to all aircraft. But the possible loss of situational awareness by pilots, controllers or ground personnel is spurring the development of an automated conflict alert. “We don’t have a lot of incursions; if they go up, they go up [at a rate of] 10 to 15 a year,” said Richard Marchi, senior vice president of technology for the Geneva, Switzerland-based Airports Council International (ACI). “But the potential for tragedy is so high that it makes sense to develop cost-effective measures, particularly those that issue a warning independently of both the (aircraft) crew and controller.”[2]

A variety of systems have been developed to sense, without pilot or tower intervention, actual and potential runway incursions. They include ASDE, airport movement area safety systems (AMASS) and satellite-based systems.

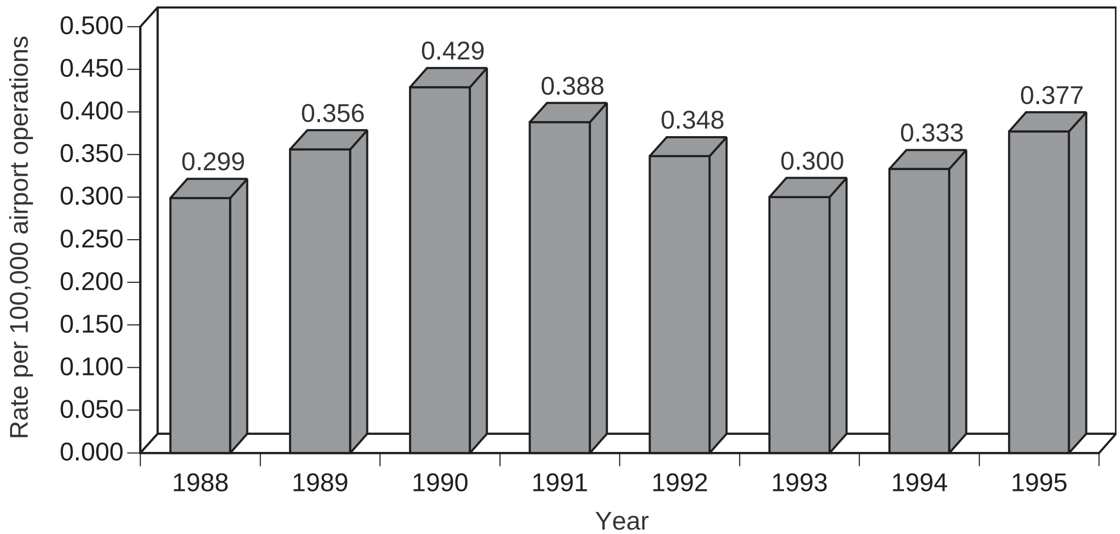
In the United States, the main ground-based effort focuses on installing ground monitoring systems at 35 medium-to-large airports. Northrop Grumman Norden Systems is supplying the equipment for the systems.

ASDE-3 is a high-resolution ground monitoring system that employs Q-band radar [operating in the frequency range of 36 gigahertz to 46 gigahertz] to expedite aircraft flow during restricted visibility conditions such as rain, snow, fog and darkness. ASDE-3 determines that aircraft are on the correct runway or taxiway, that active runways are not obstructed and that all ground traffic — airplanes, fuel trucks, emergency vehicles and others — are monitored effectively.

The system’s high-resolution displays provide an airport map overlay that can be zoomed, windowed, offset and rotated. Up to three windows can be included on each display, and target trail lengths can be adjusted by the controller to highlight target motion. Nonmovement areas are blanked, except in emergency mode, to enhance clarity.

A total of 35 airports will receive ASDE-3. The first system was commissioned at Lambert–St. Louis (Missouri, U.S.)

Total U.S. Runway Incursion Rates at Towered Airports, 1988–1995



Source: U.S. Federal Aviation Administration National Aviation Safety Data Center

Figure 2

International Airport in early 1995, and slightly more than half have been commissioned since then.

[On Nov. 22, 1994, a runway incursion accident resulted in a collision between a twin turboprop Cessna 441 and a McDonnell Douglas DC-9-82 (MD-82). The turboprop pilot and a passenger were killed. The NTSB's official accident report said that ASDE-3 radar had been installed two months before the accident. The ASDE-3 equipment had not been officially commissioned but was occasionally used by controllers for familiarization. On the night of the accident, the equipment was not available because the computer hard drive had failed, the NTSB said.[3]

[If the ASDE-3 equipment had been used on the night of the accident, "the Cessna 441's position at the intersection of taxiway Romeo and Runway 30R for three minutes before the collision would have allowed ample time for the local controller to have identified the airplane during his routine ASDE-3 scan of the runway before issuing takeoff clearance to the MD-82," the NTSB report said.

[In a video simulation during the investigation, the NTSB determined that the use of AMASS could have provided controllers with a visible and audible warning about 17 seconds before the collision. "The installation and utilization of ASDE-3, and particularly ASDE-3 enhanced with AMASS, could have prevented this accident," the NTSB accident report concluded.

[The NTSB's concern about runway incursions had been expressed in 79 safety recommendations, dating to 1972. In 1985, the NTSB conducted a special investigation study of runway incursion incidents. The report from that investigation,[4] adopted in May 1986, found that runway incursions were a human-factors issue involving controllers and pilots at all levels of experience. The study concluded that more uniformity of terminology and better verification of messages between pilots and controllers could reduce the chance of dangerously ambiguous commands or erroneous actions.]

ASDE-3 is a vast improvement over earlier-generation ASDE systems, which had poor penetration in bad weather. The new system uses an aerodynamic rotodome that sheds rain, sleet, snow and ice. It also employs frequency agility, adaptive gain, threshold control and a circular polarized antenna to maximize weather penetration.

ASDE-3 has not been used for the control of runway stop bars, but could be, if line-of-sight coverage of the required detection zones is achieved.

Multipath distortion on the ASDE-3 radar has been a problem at some airport locations. Multipath distortion is a phenomenon caused by radar reflections creating false targets on the display. Occurring at some airports and not others, the false targets appear to be on the runway, taxiing parallel to, but in the opposite direction of, real traffic using the runway. The FAA is working to reduce multipath distortion by using the target tracking software in AMASS to identify true targets and suppress false ones. The problem has caused commissioning of ASDE units to be slower than planned.

The Runway Incursion Action Plan reports that "any single type of sensor cannot prevent runway incursions. ... Without the integration of these sensors into a system that detects multiple aircraft positions and application of safety logic, alerts cannot be generated to overcome pilot, vehicle operator or controller error." AMASS is such a system.

The ASDE system is designed to be augmented by AMASS, an add-on that enhances ASDE's surveillance and collision-avoidance capabilities. AMASS can track 256 targets, and analyze surface vehicle movements to identify situations that can lead to runway incursions. The system accepts data from ASDE-3 radar as well as approach- and surface-radar inputs, and applies safety logic checks using safe operational-condition guidelines. The system then provides controllers with automatic conflict warnings and alerts, which include bright visual displays and synthetically generated voice messages. "In less than one second, AMASS tracks all ground operations, compares each movement, and automatically provides visual and audio alert of potential conflicts or even the slightest deviation in airport procedures," the FAA said.

The combined ASDE/AMASS tracks aircraft on final approach, as well as all surface targets — aircraft, vehicles, people and debris. AMASS architecture is compatible with other sensors, runway-light control, overlay of aircraft tags and data-link interfaces, and is expandable. AMASS validation testing was successfully completed at both San Francisco (California, U.S.) International Airport and Boston (Massachusetts, U.S.) Logan International Airport.

The FAA estimates that ASDE-3/AMASS installations at the 35 airports will reduce runway incursions by 25 percent nationwide. Adding the same capabilities to an additional 35 airports will reduce incursions by an additional 30 percent, to an annual level of 85 to 100 runway incursions. The FAA said that it expected AMASS to be applied systemwide by 1997.

Three enhancements that will place aircraft- and vehicle-identification tags on the ASDE/AMASS display have been demonstrated. For arrivals, identification tags have been transferred between the ASR [which provides coverage of the terminal-area and approaching traffic] data base and the AMASS target-track file. A data link has also been used to transfer differential global positioning system (GPS) data and identification for correlation with ASDE-3 data. Finally, a radar transponder has been tested that displays an identification code in response to ASDE-3 interrogations.

A combination of satellite-based systems and AMASS could also be a relatively inexpensive movement-monitoring solution

Photo: Northrop Grumman Norden

An airport surface detection equipment (ASDE) radar–outfitted tower (arrow) at Chicago O'Hare International Airport for smaller airports. Said ACI's Marchi, "ASDE is great for high-volume airports, but you want something less expensive, like a GPS solution, for smaller sites. AMASS software gets its information from radar, but it could also get it from ADS–B [automatic dependent surveillance–broadcast] from GPS-equipped airplanes."

In conjunction with the rollout of ground-based radar systems, position-monitoring capabilities based on GPS equipment and automated dependent surveillance are being developed.

Using GPS equipment to track surface movement has advantages over ground radar. First, it is more accurate. In differential GPS, a special receiver integrated into a GPS receiver decodes signals from a ground-based transmitter and applies corrections to the GPS data for known errors in the satellite signals. Differential GPS has a position accuracy of one meter to three meters [3.3 feet to 9.8 feet], and improves the ability to process target positions by safety logic. For example, at speeds below three miles per hour (4.8 kilometers per hour), there is difficulty in determining if a radar target is moving or stopped, and if a target is accelerating or decelerating without at least three radar returns from the target.

A combination of satellite-based systems and AMASS could also be a relatively inexpensive movement-monitoring solution for smaller airports.

"Positional accuracy will be sufficient to allow ground control computers and air traffic controllers to vector aircraft on runways and runway approaches," said George Donohue, FAA associate administrator for research and acquisitions. "Pilots will know their ground positions accurately, even in adverse weather, from virtually any point on an airport, and pilots will be able to retransmit this information to ground traffic-control computers. Both pilots and ground controllers will have real-time situational displays showing airport maps with their position, taxi route and clearances."[5]

Satellite-based navigation is the latest in a series of developments in surface-movement technology that begins with the ASDE-3 ground radar, adds AMASS for safety, then progresses to the FAA's next-generation airport surface traffic automation initiative, which adds target identification and automation to improve surface movement efficiency.

Next-generation research includes the use of ADS-B to track aircraft by broadcasting the aircraft's GPS position data on the Mode S message that is transmitted at regular intervals. (Mode S transponders permit individual interrogation and data transfer between the controller and the aircraft.) That allows relatively inexpensive receivers around the airport to receive position information (latitude, longitude, heading and ground speed) and feed the information to surveillance processors that track aircraft in much the same way that traffic-alert and collision avoidance system (TCAS) equipment interrogates other aircraft in the air, according to Gilbert Smoak, a staff systems engineer with Rockwell Collins Air Transport Division.[6]

A Rockwell Collins–led team demonstrated such a Mode S-based terminal area communications and surveillance system at the FAA's Technical Center in Atlantic City, New Jersey, U.S. The experiment linked two aircraft equipped with Mode S transponders, differential GPS receivers and moving map displays with the airport's SSR, a data processing system built by Unisys, and Cardion's nonrotating cooperative area precision tracking systems (CAPTS).

Elements of the same system, particularly CAPTS, have been successfully tested at Atlanta (Georgia, U.S.) Hartsfield International Airport. CAPTS includes multiple receiver/transmitter (R/T) locations that detect Mode S squitters [pulses generated by an aircraft's avionics and broadcast by the aircraft's transponder]. A central computer determines aircraft location using a process called multilateration that is based on the time the squitters are received at each R/T.

Messages are sent in short bursts at a very high data rate. That allows many aircraft to occupy a single frequency without the need for any coordination. The system is compatible with current secondary surveillance radars and TCAS II systems, and current Mode S transponders can be upgraded by service bulletins. Some prototypes are already available.

At Hartsfield, five R/Ts were installed at the north end of the airport. As many as 15 would be needed to cover the entire airport. The system has demonstrated a 92 percent reliability, and a position accuracy of better than 7.5 meters (24.6 feet). The system is also being reconfigured to test its potential application as a precision approach and runway monitor that could reduce aircraft separations on parallel runways. The U.K. Civil Aviation Authority is testing a similar system at Heathrow Airport, London, England. Experiments are being done with a British Airways Boeing 767.

A variety of systems are being developed to enhance and augment position monitoring hardware based on ground radar and GPS.

Several companies are developing digital moving map displays to aid in surface navigation, and typically display the aircraft position, the airport surface layout and sometimes other aircraft. Some problems relating to survey methods and accuracy have been encountered when adapting existing airport engineering drawings or aeronautical publications for cockpit use. The problem is avoided when maps are created using GPS survey points.

Goals of the FAA Runway Incursion Action Plan

1. Improve surface movement safety by an 80 percent reduction in runway incursions by the year 2000 from the 1990 high of 281 reported events. That goal is to be accomplished by deploying ground movement radar and developing technology to transition to satellite-based automatic dependent surveillance, and by developing lower-cost alternatives for airports that did not receive ASDE-3/AMASS.

2. Pilots and air traffic controllers should have the same expectations of performance on the airport, based on a mutual sharing of information, to improve safety, efficiency and capacity.

3. Pilots, controllers and ground vehicle operators must have clearly defined roles and responsibilities that eliminate procedural ambiguities that could cause operational errors and pilot or vehicle-operator deviations.

4. Airport visual aids necessary for guidance while taxiing should become an integrated component of the surface movement system.

5. Surface movement communications, navigation and surveillance must be able to accommodate all classes of aircraft — air carrier, commuter, general aviation, vertical flight — and necessary ground vehicles.

6. Surface movement automation should provide links between terminal and en route automation, producing a seamless, time-based operation. Automation should reduce both pilot and controller workload.

7. Ground taxi-in and taxi-out average delays should be reduced by a minimum of 15 percent from the 1990 level, and further improvements should allow for growth in operations without increases in ground delays. (The FAA estimates that 32 airports will have more than 20,000 hours of delay within the next 20 years.)

8. At airports with operations below 1,200 feet (366 meters) RVR, properly equipped aircraft should be able to land down to 300 feet (92 meters) RVR and exit the runway with sufficient guidance and procedures to allow safe taxi operations on the surface with conditions approaching zero visibility. Likewise, departing aircraft should be able to taxi out and depart down to 300 feet RVR.

9. Although benefits will flow to all airports, budget constraints dictate that technology development and acquisitions relating to surface movement safety, guidance and control should focus on the nation's large airports.

Source: U.S. Federal Aviation Administration

The Boeing Co. is working with the U.S. National Aeronautics and Space Administration (NASA) to evaluate cockpit moving maps for steering aircraft in very low visibility. The work is also associated with future development of a high-speed civil transport, *which may not have cockpit windows.*

Other manufacturers are developing moving maps with improved situational awareness aids, conflict alerts for the cockpit and tower, and color graphics to differentiate system features.

Daimler-Benz Aerospace is also using airport digital maps as an important aspect in the development of a seamless airport environment. Working with Jeppesen, Daimler-Benz is developing a taxi guidance system (TAGSY) based on satellite navigation. In addition to being an orientation tool for pilots in visual meteorological conditions or in instrument meteorological conditions, TAGSY features a differential GNSS station and data link to a surface-movement and ground-control system so the cleared taxi route will be indicated automatically.

Future enhancements to TAGSY include the presentation of obstacles received by data link, and command bars for taxi speed and nose-wheel steering. Eventually, with the addition of onboard obstacle detection and automatic speed control and nose-wheel steering, the system will offer automated taxi guidance at zero visibility.

A TAGSY demonstrator was tested by Lufthansa pilots in an Airbus A310 simulator in Hamburg, Germany, in 1995. On-site testing is planned at Cologne/Bonn (Germany) International Airport in 1997 as part of Europe's Demonstration Facilities for Airport Movements Management program. Daimler is also developing a GNSS-based flight management system that includes TAGSY capabilities.

Runway status lights are red, pulsing lights at the taxiway/runway intersection that are on when the runway is being used for takeoff or landing. The lights are activated by radar surveillance and warn of an approaching aircraft on the runway. The runway status lights project has completed proof-of-concept and flight simulator evaluations, and is being field tested at Boston Logan.♦

Editorial note: This article was adapted from *Airport Surface Movement Safety: Runway Incursion Action Plan*. U.S. Federal Aviation Administration, Report no. DOT/FAA/ASD-100/95/01. April 1995. Additional references as noted.

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