FLIGHT SAFETY FOUNDATION
Airport Operations
Vol. 28 No. 3 *For Everyone Concerned With the Safety of Flight* May–June 2002

Maintaining Visual Aids Helps to Prevent Runway Incursions

Evolving methods of inspection, evaluation and maintenance enable airports to identify deficiencies before pilots or ground personnel experience surface-navigation problems. Safety specialists in several countries are working to ensure that airport markings, signs and lighting remain visible.

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FSF Editorial Staff

In a period of heightened focus worldwide on the prevention of runway incursions and surface-navigation errors, their connection with maintenance of airport visual aids has received additional attention from many organizations. Among them, Airports Council International (ACI), the International Civil Aviation Organization (ICAO), the U.K. Civil Aviation Authority (CAA) and the U.S. Federal Aviation Administration (FAA) have initiatives under way to reduce the risk of pilots or vehicle drivers being unable to see markings, signs and/or lighting at a critical time.

Several accident/incident reports and pilot reports in the United States have identified risks involved when visual aids are not clearly visible. For example, such deficiencies contributed to the cause of a U.S. runway incursion and collision involving a McDonnell Douglas DC-9 and a Boeing 727 on December 3, 1990. The U.S. National Transportation Safety Board (NTSB), in its final report, said, "It appears likely that by 1341 [local time], the pilots had abandoned their attempts to compare what they saw on the Jeppesen airport diagram with their observations from the cockpit. They began to rely totally on the airfield signs and markings they observed through the fog to comply with the ground controller's instructions. … The inner taxiway centerline from Gate C18 eastbound to past the fire station was visible. However, about 200 feet [61 meters] of the centerline as it curved through the Oscar 6 area varied in conspicuity between 'very faded' to 'not visible' under day [visual meteorological] conditions, according to the investigators who observed the taxiway." Among resultant safety recommendations, NTSB said that the airport should "implement a program to provide for the prompt repainting of faded taxiway and runway markings when they are seen during daily airport inspections, rather than waiting for a set schedule for overall airport restriping."[1]

ICAO provides standards and recommended practices (SARPs) that influence how airports maintain visual aids, requires a system of preventive maintenance to ensure the reliability of lighting and marking systems, and recommends that such systems keep visual aids (and other facilities) in a condition that "does not impair the safety, regularity or efficiency of air navigation."[2] This includes the implementation of standards of preventive maintenance to ensure the serviceability of the following: approach lights and runway lights for Category II/Category III precision approach runways, stop bars — defined in ICAO Annex 14, *Aerodromes*, Volume 1, paragraph 5.3.17, 'Stop Bars,' as lights spaced at intervals of three meters (9.8 feet) across the taxiway, showing red in the direction(s) of approach — provided at a runway-holding position used in conjunction with a runway intended for operation in runway visual range (RVR) conditions less than 350 meters (1,200 feet), and runways meant for takeoff in RVR conditions less than 550 meters (1,800 feet). The

standards include criteria for determining when a light fixture is unserviceable, percentages of serviceable lights required by type of light and the permissibility of adjacent unserviceable lights of various types.[3]

ICAO specifications of the colors for airport markings, signs and panels also say, "The specifications of surface colors given below apply only to freshly colored surfaces. Colors used for markings, signs and panels usually change with time and therefore require renewal."[4]

In the United States, FAA guidance for developing a surface movement guidance-and-control system (SMGCS) also includes maintenance criteria for lighting aids and lighted signs. For example, they include addressing immediately any two adjacent unserviceable lights or reflectors among the taxiway edge lights, taxiway edge reflectors and taxiway centerline lights along the low-visibility taxi route. Alternative procedures should be implemented or low-visibility operations should be terminated in several circumstances of unserviceable lighting aids. Similarly, FAA said, "Mandatory-instruction signs, at entrances to the active low-visibility runway(s), and location and direction signs, along low-visibility taxi routes where aircraft will be required to hold or turn, should be inspected prior to implementation of SMGCS procedures, and every two [hours] to four hours while the SMGCS plan is in effect."[5]

ICAO Visual Aids Panel Develops Maintenance-related Amendments

Jean-Noel Massot, airport technology policy specialist for Aéroports de Paris, France, and representative of Airports Council International (ACI) to the ICAO Visual Aids Panel (VAP), said that major improvements to ICAO SARPs have been under development, including some that will affect the maintenance of airport visual aids.[6] Major issues for VAP related to markings, signs and lighting since the last amendments to Annex 14 in 1999 have included the installation of stop bars with air traffic control (ATC) control interface, change of all signs to provide a letter designation for taxiways and to provide larger sizes of signs, and photometric measurement of aeronautical ground lighting performance.

Attempts have been made to develop common procedures, methods or equipment for maintaining visual aids, but current practices of the world's airports primarily are based on general lighting rules because of variability in conditions of use, weather, temperature and traffic levels, Massot said. Amending maintenance-related SARPs for visual aids is an ongoing task that coincides with the four-year revision cycle of Annex 14, in which each set of amendments effects changes at airports.

"A major concern during this revision cycle is the use of visual aids for safety of operations on the runways," Massot said. "Maintenance requirements for visual aids also have been in development since 1999. As part of this effort, in summer 2002, ACI prepared a restricted survey report about the practice of on-site photometric measurement of aeronautical ground lighting, which is recommended for Category II/Category III precision approach runways. These measurements have been used to improve cleaning performance — especially at busy airports where lighting performance of inset lights deteriorates quickly."

ACI's survey results from airports in Europe, the Americas and Asia showed that some currently are experimenting with on-site photometric measurement and others already have implemented the technology. The airports were not identified in the report. The airports using photometric technology told ACI that maintaining inset ground lighting, especially runway centerline lighting and touchdown zone lighting, has been their most difficult problem because of the frequency of contamination by aircraft tires and because of the rate of aging/deterioration of light-fixture lenses. Related interests of the airports using photometric technology have been optimizing maintenance efficiency to reduce the length of time that runways are closed for cleaning or maintenance of aeronautical ground lighting, and planning how often to clean light fixtures and to replace lamps, Massot said.

The technology to measure cleaning performance also has increased airports' interest in improved cleaning methods (for example, using soft brushes, steam and mild walnut-shell abrasives rather than pressurized hot water to remove rubber dust and rubber deposits from lenses).

"The basic principle for aeronautical ground lighting is that physical maintenance is the primary way to continue the effectiveness of any lighting installation," Massot said. "Frequently, new airports include a light-by-light failure-detection system that provides an automatic, continuous status report that makes maintenance of lights more efficient. The deterioration of elevated lights and signs typically is much slower than for inset lights, and is handled with normal maintenance practices such as monthly cleaning unless they are electrically unserviceable. Visual inspections are also the method of checking markings, which deteriorate under hot weather conditions and winter weather conditions."

U.K. CAA Requirements Will Address Lighting Issues

In January 2002, U.K. CAA published Notice to Aerodrome Licence Holders (NOTAL) 1/2002, "Aeronautical Ground Lighting Requirements," outlining new requirements that will be effective for U.K. airports on Jan. 1, 2004, based on anticipated amendments to the SARPS in Annex 14. The requirements take into account U.K. CAA surveys of photometric performance data for aeronautical ground lighting at U.K. airports, a review of current requirements and maintenance practices, the ongoing work of ACI, pending decisions and actions to be taken by VAP at its November 2002

meeting, and methods by which airport operators will be required to demonstrate regulatory compliance using photometric measurements.

The NOTAL said, "The new SARPs permit the number of lights required for operations in visibility conditions of [RVR] less than 550 meters to be reduced, provided it can be demonstrated that the performance of the [aeronautical ground lighting] meets the specified serviceability levels. The SARPs also recommend the implementation of [aeronautical ground lighting] photometric measurement using a mobile device as a means of maintaining serviceability levels. … The [U.K. CAA survey] research, described in NOTAL 3/97, included many photometric surveys on operational runways in the [United Kingdom]. The results showed that virtually all of the [aeronautical ground lighting] surveyed failed by significant margins to meet the minimum standards outlined in Appendix 2 ['Aeronautical Ground Light Characteristics'] of Annex 14 Volume 1, reproduced in [U.K. CAA Civil Aviation Publication (CAP) 168, *Licensing of Aerodromes*] at Chapter 6 ['Aeronautical Ground Lighting'], Appendix 6A ['Aeronautical Ground Lighting Characteristics']."

Poor installation and inadequate maintenance, especially cleaning, were the primary causes of poor performance found by the researchers. U.K. CAA also said that an underlying problem in current SARPs for aeronautical ground lighting was revealed.

The NOTAL said, "However, more fundamentally, it was revealed that the ability of the [aeronautical ground lighting] to meet the minimum standards was severely limited because the individual components of the [aeronautical ground lighting] system, including the light fittings, were manufactured in most cases to a specification designed to meet the minimum standards and no more, thereby not allowing for any deterioration of the system as a whole. … The [U.K. CAA review of requirements and maintenance practices] concluded that it might not be possible for a U.K. aerodrome to improve the performance of its existing [aeronautical ground lighting] in order to achieve and maintain the published standards. In addition, it was cited that there are few reported incidents attributed to poor [aeronautical ground lighting] performance, although a reason for this may be because a pilot is normally unable to determine whether a light is of the correct intensity and should have been visible, or whether visual cues are trustworthy."

U.K. CAA will not consider reduction of the number of lights required for certain operations until U.K. airports are able to demonstrate the performance of their current aeronautical ground lighting with data, and the broader performance issue has been addressed, the NOTAL said.

"[Aeronautical ground lighting for approach lights and runway lights] should be focused on assuring maximum availability of lights that are of the correct intensity and alignment, which the existing practice of measuring and monitoring lamp failures and primary series circuit current cannot do," the NOTAL said. "The only current means of determining the true performance of [aeronautical ground lighting] is to perform some form of photometric measurement and a visual assessment. … A difference of 50 percent intensity between two adjacent lights, where one light is of the required intensity, is considered to be the smallest deficiency that an unaided eye can detect during flight inspection in clear visibility conditions. However, it was not intended that every light should perform just above the [ICAO-required] 50 percent value that this double standard would appear to allow."

U.K. CAA said that despite the performance issues identified, a typical airport with medium traffic type and traffic density — by adopting photometric measurement as part of a robust program for maintenance of airport visual aids — should be able to demonstrate an overall performance level of at least 70 percent of the specified minimum.

"On a runway with a high movement rate and heavy aircraft types, it may not be possible to attain this level of [aeronautical ground lighting] performance; however, [aeronautical ground lighting] maintained this way displays a significantly improved, balanced pattern, which is probably of more value to pilots in the visibility conditions that are most usually encountered, and can be easily verified by a flight inspection, as outlined in NOTAL 3/00," the NOTAL said. "A light [in approach lighting and runway lighting systems] shall be deemed unserviceable if its average luminous intensity is, for any reason, less than 50 percent of the average luminous intensity specified in the relevant isocandela diagram in CAP 168 at Chapter 6 Appendix 6A, or if the brightest part of the beam is not within the specified beam area."

U.K. airport operators will be expected to meet or exceed this standard, but if they cannot after implementing photometric measurement, they must establish and maintain the best photometric performance level achievable in their operational environment, subject to U.K. CAA audit after the date that the requirements take effect. Responding to this guidance, one U.K. airport operator said that significant insights already have been gained.

Manchester Airport Measures Ground Lighting Performance

The addition of many signs, markings and types of ground lighting since the mid-1990s, and the completion of Runway 06R/24L in February 2001, prompted Manchester Airport in the United Kingdom to reassess methods of maintaining visual aids, said Debbie Riley, airfield policy and planning manager, Airport Operations.[7]

Some changes in visual aids, including maintenance practices, have been influenced by ongoing communication

processes, Riley said. For example, pilots sometimes tell ATC that they want to speak to an Airport Operations representative about a problem or concern. More commonly, issues involving visual aids arise during bimonthly meetings of the Manchester Airport Pilot Technical Working Group, a forum involving airport staff, ATC and pilots of airlines based at the airport. An annual survey — collecting data from printed forms distributed by the working group's members to pilots, e-mail questionnaires and pilot interviews — has been used to identify areas for improvement, she said. U.K. CAA mandatory occurrence reports are another routine source of information that affects visual aids.

"We have frank and open discussions about how airfield operations — including markings, lighting and signs — affect pilots," Riley said. "For example, when new signs were installed for Runway 06L/24R operations, certain signs created problems despite planning. The pilot's eye view from various aircraft types was not the same as viewing signs from a ground vehicle, so some signs were moved slightly based on recommendations and comments from pilots. Now, after a long period of very poor weather, a pilot might say, 'The paint on this marking is wearing a little thin — can you put that on your list?' But our view is that if a pilot has a concern, we have fallen down because the majority of the time, our inspectors identify and address maintenance needs at the source before they become apparent to anybody else."

The airport currently uses the following procedures, Riley said:

- Safety officers and duty officers look for early indications of wear on markings, unserviceable signs and failures of lights as they conduct daily visual inspections of the entire airport;

- The program requires renewal (cleaning and/or repainting) of painted markings at least annually, and areas affected by heavy traffic are renewed two times per year or three times per year;

- Some airport staff in the maintenance unit have been assigned permanently to grass cutting, painting of runway/taxiway/apron markings and minor taxiway repairs;

- The maintenance unit has machines for degreasing, cleaning and painting that enable them to schedule cleaning/repainting operations between night aircraft operations on Runway 06L/24R (which is used for all night operations) and anytime during night hours on Runway 06R/24L;

- Markings for aprons and stands (gate areas) are degreased and renewed as often as required based on the daily inspections, typically more frequently than taxiways and runways because the markings often are contaminated and obscured by lavatory-fluid spills, grease, oil, diesel fuel and hydraulic fluids; and,

- The maintenance unit also is responsible for renewing annually (or as required) the anti-slip, green-painted walkways that guide pedestrians on aprons where the gates do not have airbridges (commonly called passenger-loading bridges, jetbridges and jetways in other countries, airbridges are installed at airport gates to provide movable, telescoping-tunnel sections with an adjustable canopy that is docked against the main boarding door[s] of an aircraft to provide a secure and weather-tight connection between a specific gate area and the aircraft). These markings also identify the walkways so that handling agents and other ground vehicle drivers will not park vehicles on the walkways.

The decision to use airport staff rather than a contractor to renew markings was based, in part, on the difficulty of scheduling painters around frequent periods of rainy weather.

"In some areas, such as outer taxiways, the unit just paints over the top of existing markings," Riley said. "If we have, over a number of years, a buildup of paint that is so thick that it cracks, the unit will remove the paint and begin again. Usually markings with several layers of paint last longer than those with one layer of new paint — for example, paint markings on our new runway have not lasted as long as multi-layer markings elsewhere on the airfield. We do not have a scientific basis to evaluate the wear of painted markings; the staff of the unit decides whether or not the markings need to be renewed based on visual evaluation."

In developing the maintenance program for markings, the airport introduced methods of making some markings more conspicuous by exceeding ICAO SARPs. One example was the introduction of black edge lines wherever yellow taxiway centerlines are painted on light-colored surfaces.

"We have edged in black everywhere we have light surfaces, including the surface markings for the stop bars and for intermediate stop bars, which are markings only," she said. "Edging in black really makes them show up and reduces the risk of a pilot missing [overlooking and taxiing beyond] a stop bar."

In renewing markings, airports in the United Kingdom follow standards for chlorinated rubber paint, a nonreflective type without nonslip additives, established by U.K. CAA.

"Manchester Airport was the first major airport in the United Kingdom to change signs to conform to the latest ICAO Annex 14 requirements," Riley said. "All our signs are less than five years old, and all have internal lighting per ICAO SARPs, so we have not had any major issues as we conduct physical inspections of signs on a daily basis to ensure that any lights out are reported straightaway. Any faults are corrected quickly,

most within a few hours, by airfield-lighting engineers who carry replacement supplies such as lamps. We do not have a sign-replacement program because we have not had any serious problem with sign outages."

Signs — like Manchester Airport aeronautical ground lighting for night operations and low-visibility operations — are illuminated continuously during those conditions rather than being turned on and turned off as needed. This decision was based on the airfield-lighting engineers' monitoring of lamp life under both methods.

"When we looked at potential cost savings of turning off Runway 06R/24L signs, for example, we found that the strain, shown by lamp failure rate, was greater than when lamps were illuminated continuously," Riley said. "During the day, signs are illuminated only during low-visibility procedures. Signs are tested when installed, but thereafter, sign maintenance becomes subjective."

Visual aids at Manchester Airport include a mixture of lighting of older types and the most current types. All taxiways have green centerline lighting; blue taxiway edge lighting has been used supplementally on curved sections. Runway 06L and Runway 24R are used for Category III operations and they have associated touchdown zone lighting, approach lights and flush runway-edge lights.

Manchester Airport has been one of the first airports in the United Kingdom to implement a program that anticipates the new U.K. CAA regulatory requirements in NOTAL 01/2002. Airport operators will be required to demonstrate with data that their aeronautical ground lighting meets standards for performance.

To do this, the airport has initiated a program of night photometric measurement of runway centerline lights twice per week, and edge lights and touchdown zone lights weekly. The primary measurement equipment is a computerized array of sensors mounted on a mobile trailer. The sensors are pulled over light fixtures at speeds up to 40 miles per hour (64 kilometers per hour) while the lighting is set to the highest intensity level. The position of each fixture is determined using global positioning system (GPS) technology and photometric maps (showing performance of fixtures) are printed out from a laptop computer. The equipment is supplemented by handheld photometric devices on the trailer — required for some types of fixtures and for bench-test measurements in the maintenance shop.

"We were hoping that routine photometric measurement would dramatically improve the quality of lighting on runways, and it is proving to do that," Riley said. "We are going beyond international standards in this critical area, just as we have provided touchdown zone markings and a CAA-mandated aiming point, both exceeding Annex 14 and reported to ICAO as differences compared to SARPs."

Photometric measurement to verify the initial performance of lighting fixtures after installation has been a part of SARPs for many years, said Mike Curry, airfield duty manager of Manchester Airport. Diagrams in Annex 14 have specified for manufacturers the minimum light output, in isocandelas, that each type of lighting fixture must produce when new. Independent test centers measure the light output and certify that the fixtures meet this standard.[8]

"Test centers produced photometric diagrams of light output, and when airports installed the fixture in the ground, people assumed that this was the light output that the fixtures would continue to produce," Curry said. "Until recently, no technology was available for us to determine later the performance of the lighting installation. Lamp replacement typically has been performed using a time-based method or a visual method — if the fixture looked a bit dark, we cleaned it; if it failed, we put in a new lamp. These methods came down to subjective individual decisions. Now technology is available to measure routinely photometric performance in the field. Annex 14 says that the lighting installation should be maintained so that it never falls below 50 percent of its photometric performance when new."

Since the introduction of photometric measurement, Manchester Airport has found that the actual performance of lighting fixtures that appeared to be serviceable can vary from about 30 percent to about 70 percent of the required photometric performance when new. The objective method of measurement has enabled the airport to establish a higher, more consistent level of performance for aeronautical ground lighting, he said.

"Nobody knew before about this variation — because of photometric measurement, our aeronautical ground lighting overall has been smoothed out to a more constant level rather than having big changes over a period of time," Curry said. "We have provided our maintenance staff a high standard to achieve, and we made dramatic changes in our maintenance regimes around that level of performance. The amount of maintenance has increased dramatically to be able to maintain performance to the standards in Chapter 6 of CAP 168 and NOTAL 1/2002, using photometric measurement. Most important is cleaning the fixtures, because one big rubber deposit by a wide-body aircraft can wipe out the required performance of a light fixture; we also know that deicing fluid makes light fixtures sticky and more dirt sticks to them in the winter months."

Photometric measurement complements visual inspection, which is still required to detect loose bolts, damaged lenses, water infiltration and other problems, Curry said.

"We believed that our former maintenance regime was good: nightly inspections for lamp failures and waiting 13 weeks between scheduled service," he said. "When we began photometric measurement, we were very surprised at the

results: the difference between failure and high performance could not be detected with the human eye. Every night we are doing a little cleaning, monitoring and targeted maintenance, including lamp changes, rather than intensive maintenance for three weeks at a time. There has been a change of regime, not an increase in labor. We had to rethink our whole maintenance practice and procedure, but in the past few months, we have received comments from pilots about how good the lighting system has been — they do appreciate the high standard of the system."

FAA Develops Repaint Criteria for Markings

The most recent FAA initiatives to monitor maintenance of airport visual aids for runways and taxiways include development of standardized techniques for evaluating painted markings, basic research on visual aids and related human factors, and training of FAA flight operations inspectors to report unserviceable markings, signs and lighting during their routine operations, said Ben Castellano, manager, FAA Airport Safety and Certification Branch. These activities were proposed in FAA's *National Blueprint for Runway Safety* in October 2000.[9]

"Technological advances that we have adopted — wider use of runway guard lights, both elevated and in-pavement; controllable [stop bars] and noncontrollable stop bars; glass beads in many of the markings; and outlining the holding position markings in black on light-colored pavement — require [airport] maintenance personnel to be familiar with more sophisticated equipment and procedures than ever before," Castellano said.

FAA research and development staff will publish in 2002 a report on repaint criteria for airport surface markings, Castellano said. The project at the William J. Hughes Technical Center in Atlantic City, New Jersey, U.S., has evaluated a manual method and an automated method that could be used by an airport operator or by an FAA airport certification safety inspector to determine objectively when the markings need to be repainted. The methods under study have included criteria for the visual inspection of paint coverage combined with the use of measurements taken with a retroreflectometer and a chromaticity meter, said Holly Cyrus, project manager. The project has included meetings and field testing of the proposed methods with FAA inspectors, she said.[10]

MITRE Corp., an FAA contractor, is reviewing U.S. airport surface markings to determine how they can be improved in terms of colors, shapes and human factors, Castellano said.

FAA's Runway Safety Program Office initiated the program for flight operations inspectors, involving the FAA Flight Inspection Operations Division under Aviation Systems Standards, he said. The division tests navigational aids for operational accuracy at all airports that have this equipment.

"[Flight inspection] crews look at the signs and marking as they taxi around different airports," Castellano said. "If they see any area that they might find confusing or lacking in appropriate signs and markings, they will pass on the information to our airport certification safety inspectors, who then will review the finding and, with the airport operator, decide if there needs to be any sort of change."

To help ensure that visual aids remain clearly visible, ICAO provides the following general recommendations:[11]

- Programs for maintenance of lighting fixtures should involve procedures and cleaning methods matched to the sources and frequency of contamination; for example, dust deposited by wind and rain typically can be removed easily from edge lights and elevated approach lights, but severe contamination from sources such as rubber deposits and engine exhaust deposits require different methods and schedules for inset aeronautical ground lighting;

- For practical reasons, lamps in aeronautical ground lighting should be replaced when the output of the fixture drops below 70 percent of the intensity when new;

- Field measurements should be conducted regularly to respond appropriately to reductions of light output, and beam misalignments should be adjusted in a workshop;

- Records of lamp life, including factors such as percentage of operational time at the highest intensity level, number of on/off cycles and exposure to dynamic stresses (wheel loads and temperature extremes) in the environment should be used to anticipate replacement needs;

- The program for maintaining signs should include frequent attention to the integrity and legibility of information; ensuring serviceable internal/external lighting of signs; removing contamination and obstructions; and repositioning/repairing damaged signs as required; and,

- Inspection of all surface markings should be conducted at least twice per year to detect weather-related deterioration, need for repainting because of fading, cracking, discoloration by soil and damage caused by the removal of rubber deposits from pavement.

Methods for objective evaluation of airport visual aids enable airports to use resources efficiently while ensuring that their standards for visibility of markings, signs and lighting are met consistently. Some airports anticipate that data-driven optimization of routine lamp replacements (in addition to on-condition replacements) and cleaning intervals for their

aeronautical ground lighting soon will be possible. Comparable advances for other visual aids, some already on the horizon, will contribute measurably to safer operations — especially at night and during low visibility.♦

Notes

1. U.S. National Transportation Safety Board (NTSB). Aircraft Accident Report no. NTSB/AAR–91/05. *Northwest Airlines, Inc. Flights 1482 and 299 Runway Incursion and Collision, Detroit Metropolitan/Wayne County Airport, Romulus, Michigan, [U.S.], December 3, 1990.* The report said that the two aircraft collided near the intersection of Runway 09/27 and Runway 03C/21C in dense fog. The Boeing 727 was on its takeoff roll and the DC-9 had just taxied onto the active runway. One of the four crewmembers and seven of the 39 passengers aboard the DC-9 were killed, and the aircraft was destroyed. None of the 146 passengers and 10 crewmembers on the B-727 was injured; the aircraft was substantially damaged. NTSB said that the probable cause of the collision was "a lack of proper crew coordination, including a virtual reversal of roles by the DC-9 pilots, which led to their failure to stop taxiing their airplane and alert the ground controller of their positional uncertainty in a timely manner before and after intruding onto the active runway." The report said, "Contributing to the cause of the accident were (1) deficiencies in the air traffic control services provided by the Detroit Tower, including failure of the ground controller to take timely action to alert the local controller to the possible runway incursion, inadequate visibility observations, failure to use progressive taxi instructions in low-visibility conditions, and issuance of inappropriate and confusing taxi instructions compounded by inadequate backup supervision for the level of experience of the staff on duty; (2) deficiencies in the surface markings, signage and lighting at the airport and the failure of [U.S.] Federal Aviation Administration surveillance to detect or correct any of these deficiencies; and (3) failure of Northwest Airlines, Inc. to provide adequate cockpit resource management training to their line aircrews."

2. International Civil Aviation Organization (ICAO). Annex 14, *Aerodromes*, Volume I, paragraph 9.4.1.

3. ICAO Annex 14, paragraph 9.4.26 through paragraph 9.4.31.

4. ICAO Annex 14, Appendix 1, "Colours for Aeronautical Ground Lights, Markings, Signs and Panels," note to paragraph 3.1.

5. U.S. Federal Aviation Administration. Advisory Circular 120–57A, "Surface Movement Guidance and Control System." Dec. 19, 1996.

6. Massot, Jean-Noel. Telephone interview with Rosenkrans, Wayne. Alexandria, Virginia, U.S., July 5, 2002. Flight Safety Foundation, Alexandria, Virginia, U.S.

7. Riley, Debbie. Telephone interview with Rosenkrans, Wayne. Alexandria, Virginia, U.S., July 4, 2002. Flight Safety Foundation, Alexandria, Virginia, U.S.

8. Curry, Mike. Telephone interview with Rosenkrans, Wayne. Alexandria, Virginia, U.S., July 5, 2002. Flight Safety Foundation, Alexandria, Virginia, U.S.

9. Castellano, Ben. Email communication with Rosenkrans, Wayne. Alexandria, Virginia, U.S., July 5, 2002. Flight Safety Foundation, Alexandria, Virginia, U.S.

10. Cyrus, Holly. Telephone interview with Rosenkrans, Wayne. Alexandria, Virginia, U.S., July 5, 2002. Flight Safety Foundation, Alexandria, Virginia, U.S.

11. ICAO. Part 9. *Airport Maintenance Practices.* Chapter 2, "Maintenance of Visual Aids." Section 2.6, Section 2.7 and Section 2.8.

Further Reading From FSF Publications

FSF Editorial Staff. "Airfield Driver Training, Enforcement Help Prevent Aircraft-vehicle Collisions." *Airport Operations* Volume 26 (September–October 2000).

FSF Editorial Staff. "Methods of Preventing Runway Collisions Evolve in Europe and the United States." *Airport Operations* Volume 26 (July–August 2000).

FSF Editorial Staff. "Ramp Incidents Take Toll in Equipment Losses and Personnel Injuries." *Airport Operations* Volume 22 (September–October 1996).

Rosenberg, Barry. "Radar Technology, Satellite Systems at Forefront of Global Effort to Reduce Runway Incursions." *Airport Operations* Volume 22 (March–April 1996).

FSF Editorial Staff. "Pilot of Cessna 441 Incorrectly Taxis Onto Active Runway and Aircraft Is Struck by McDonnell Douglas MD-82 on Takeoff Roll." *Accident Prevention* Volume 53 (March 1996).

Koenig, Robert L. "FAA Report Surveys U.S. Airline Pilots to Discover Factors That Promote Runway Incursions." *Airport Operations* Volume 21 (July–August 1995).

FSF Editorial Staff. "Runway Incursions and Incidents Remain Safety Issues." *Airport Operations* Volume 19 (July–August 1993).

Pope, John A. "Anatomy of a Runway Collision." *Accident Prevention* Volume 48 (October 1991).

Call for Nominations

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