Thorn Airfield Lighting

BREAK, DISTORT or YIELD

Updated approach lighting system standards address risks during the 100-millisecond impact of an airplane.

BY WAYNE ROSENKRANS

If an airplane strikes an approach lighting system (ALS), the severity of aircraft damage and likelihood of occupant injuries primarily depend on the ALS design. With this in mind, a 25-year-old ALS safety initiative this year produced its final product: *Frangibility,* Part 6 of the International Civil Aviation Organization (ICAO) *Aerodrome Design Manual.* The new part covers not only ALS but many other visual and nonvisual navigation aids installed by necessity within airport operational areas.

ICAO defines a frangible object as having "low mass designed to break, distort or yield so as to present the minimum hazard to aircraft." A frangible ALS design can involve lightweight materials, intentionally brittle or weak structural members and/or connections, and proven break-away or failure mechanisms such as disintegration during impact.

Design engineers in several countries began cooperating in the 1970s on reducing the hazards of aircraft–ALS collisions. Part 6 of the ICAO manual reflects their extensive full-scale dynamic testing of ALS designs in the early 1990s and a series of dynamic tests and computer simulations from 1998 through 2004.

A frangible ALS can reduce outcome severity in scenarios such as the December 2000 incident in which a Delta Air Lines McDonnell Douglas–Boeing MD-90 landed short of the threshold of Runway 34R during an instrument landing system (ILS) approach in poor weather at Salt Lake City International Airport. No injuries occurred; the left main wheel splash guard was damaged, the no. 2 tire was cut, a 1-inch square (6.5 sq cm) piece of metal was lodged in the left engine noise-suppression material, and the left engine fan section was damaged. FAA's incident report said, "Upon reaching the gate, the captain notified the control tower that he had 'possibly touched down short of the runway.' … Subsequent inspection revealed debris on Runway 34R. The airplane [had] struck the approach lights 400 ft [122 m] short of the runway. Two threshold lights and one light each from the 100-ft [30-m]

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and 200-ft [61-m] approach light bars were found knocked off."

Global accident and incident records show that aircraft–ALS collisions have directly and indirectly caused fatalities. For example, after the June 1999 American Airlines Flight 1420 overrun accident involving an MD-82, the U.S. National Transportation Safety Board (NTSB) said, "The FAA determined that the Runway 22L [ALS] at Little Rock [Arkansas], which is located in a flood plain area of the Arkansas River, could not be retrofitted to a frangible design because of the possibility that moving water, ice and floating debris would affect the structural integrity of the system. … The airplane's collision with the nonfrangible lighting system was the direct cause of the fatal blunt-force-trauma injuries sustained by the captain and the passengers in seats 3 and 8A and [damage; see related article on page 28] on the left side of the fuselage."

One example of loss of control following an aircraft–ALS collision occurred in May 2002, when six crewmembers, 67 passengers and 30 people on the ground were killed; one passenger, one crewmember and 24 people on the ground were seriously injured; and the aircraft and more than 25 buildings were destroyed by impact and post-impact fire after a British Aerospace BAC One-Eleven Series 500 operated by EAS Airlines struck approach lights during takeoff from Kano Airport, Nigeria, according to Ascend. The following occurrences, which involved no injuries to aircraft occupants, also were reported by Ascend:

- In April 2004, the flight crew of an Airbus A340-310 operated by Emirates overran Runway 21R on takeoff at Jan Smuts International Airport, Johannesburg, South Africa, continued through the approach lights for about 150 m (492 ft) — during which three tires burst and the flaps were jammed in the takeoff position — and completed the takeoff; they jettisoned fuel, and four more tires failed during landing at the departure airport.

- In June 2004, the aircraft received minor damage when an A300 B4-200 operated by EgyptAir overran Runway 18 at Khartoum (Sudan) Airport and traveled through the ALS onto rough ground.

- In January 2005, a Boeing 747-200F operated by Atlas Air overran Runway 23L at Düsseldorf (Germany) International Airport and struck the ALS and the instrument landing system (ILS) before coming to a stop.

ALS Installations Vary

Dr. Ir. Jaap Wiggenraad, a research engineer who has specialized in ALS frangibility research and business manager of the Aerospace Vehicles Division of National Aerospace Laboratory (NLR)–Netherlands, considers the most relevant advance of 2006 to be increased awareness of the need for frangible ALS installations. "Awareness also applies to other structures at airports such as ILS towers — the key is lightweight design, whereas the tendency was to build robust structures to withstand weather, vandalism, abuse, etc.," Wiggenraad said.

NLR has observed significant variation among frangible ALS designs that comply with current standards and among those that do not. "I think a few providers exist in Canada, Finland, the United States, Germany and Norway, each with a different concept," Wiggenraad said. "In many Western countries, frangible systems have already been placed. Elsewhere, you may find improvised, locally constructed systems."

A European company that tracks airport compliance with frangible ALS standards also sees room for improvement in some regions. "Part 6 requirements differ quite a lot from the [ICAO] 1991 Interim Guidance on Frangibility, [and] some installations which conformed to interim guidance may not comply with Part 6 [— such as in] new limitations [on] frangible behavior of a mast," said Jaakko Martikainen, sales manager, airport products, for Exel Oyj, a manufacturer of ALS poles and lattice-type masts based in Finland. Specifically, earlier designs with relatively long distances between frangible points in their break-away or failure mechanisms may not comply, he said. "We have estimated that some 85 to 90 percent of European and North American airports have been upgraded," Martikainen said. "Outside of these [regions], the overall percentage is far below 50 percent, with some positive exceptions. We are talking about quite large numbers that require replacement."

Early frangible ALS designs can be traced to FAA research during the 1970s. "These structures consisted of hollow poles made of aluminum or glass/epoxy, aluminum truss structures and an aluminum tripod structure of an originally Swedish design," one report said. "Initial engineering analysis suggested that the important parameters required to define frangibility were the peak force occurring during the impact, the energy absorbed during the contact period and the duration of the impact."[1]

ICAO's Frangible Aids Study Group — formed in 1981 with members from Airports Council International, Canada, The Netherlands, the United Kingdom and the United States who last met in 1998 and 2003 — was

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disbanded upon completion of Part 6, according to Sue-Ann Rapattoni, an ICAO spokeswoman, although related standards were implemented on earlier dates as specified in Annex 14, Volume 1, *Aerodromes.* States were expected to comply with a protection date of Jan. 1, 2005, for their existing elevated approach lights. "The new [design] guidance took effect in June 2006," she said.

Closely associated with several ICAO annexes, Part 6 has been written to reduce the risk of an accident primarily by making the ALS "frangible and mounted as low as possible to assure that impact will not result in loss of control of the aircraft." ICAO's goal is to help states implement Part 6 specifications so that guidance on design is applied uniformly, Rapattoni said. The following excerpts summarize the key concepts of a frangible ALS:

- "A frangible structure should … break, distort or yield readily when subjected to the sudden collision forces of a 3,000-kg [6,614-lb] aircraft airborne and traveling at 140 km/h (75 kt) or moving on the ground at 50 km/h (27 kt). … To allow the aircraft to pass, the failure mode of the structure should be one of the following: fracture; windowing [opening a space]; or bending."
- "Elevated approach lights and their supporting structures should be frangible except that, in that portion of the approach lighting system beyond 300 m [984 ft] from the threshold, where the height of a supporting structure exceeds 12 m [39 ft], the frangibility requirement should apply to the top 12 m only; and where a supporting structure is surrounded by nonfrangible objects, only that part of the structure that extends above the surrounding objects should be frangible."
- "The location of break-away or failure mechanisms should be such that disintegration results in components of predictable mass and size, which, in case of secondary impact, do not present a greater hazard [to the aircraft] than they present as part of the undamaged structure."
- "The design materials selected should preclude any tendency for the components, including the electrical conductors, etc., to 'wrap around' the colliding aircraft or any part of it. … After a collision, the structure should not become entangled with the aircraft in a manner that will prevent the aircraft from maneuvering safely either in flight or on the ground. … In the case of towers that may be impacted by airborne aircraft, it is desirable to not only minimize the amount of damage to the aircraft but also to not significantly impede the flight trajectory."
- "It is recommended that [electrical] conductors be designed such that they do not rupture but break at predetermined points within the limits for frangibility of the structure. … In addition, the connectors should be protected by a break-away boot … to contain any possible arcing at disconnection."

Among influences on Part 6 was a study published in 2004 by National Research Council Canada (NRCC), comparing full-scale dynamic impact testing of airport approach lighting towers using truck-mounted impactors with computer simulation. "The objective … was to simulate the transient dynamic impact," said the report. "There was good correlation between deformation mode, location and timing of failure, impact force and energy absorption curves obtained from full-scale test results and simulation. Evaluation of the model showed that it was computationally stable, reliable and repeatable."[2]

David Zimcik, Ph.D., one of the NRCC researchers, in April 2006 noted that computer simulation reduces costs. "Dynamic testing is expensive and dangerous; it's also difficult because there are so many parameters to investigate," Zimcik said. "The analytic tools we're developing allow us to become proactive — to design in [frangibility] as opposed to [designing] after-the-fact, so that fewer tests are required. Airplanes do hit towers. We wanted to understand the phenomena so we could design a safer tower. That was the driver." As a result of such studies, Part 6 allows validated computer simulation of aircraft–ALS collisions to prove frangibility.

Advisory Circular Update

A few months after Part 6 was published, FAA issued an advisory circular (AC) embodying the current state of U.S. and ICAO research and experience in the agency's ALS Improvement Program (ALSIP), which began in 1978. The Airport Engineering Division issued AC 150/5345-45B, *Low-Impact Resistant (LIR) Structures,* on Sept. 5, 2006. "The most significant advance is the work being done toward the approval of the use of frangible bolts for anchoring devices," said Paul Takemoto, an FAA spokesman. "FAA intends to use the force and energy standards in Part 6 in establishing performance standards for the approval of frangible bolts, called 'fuse bolts' in Part 6."

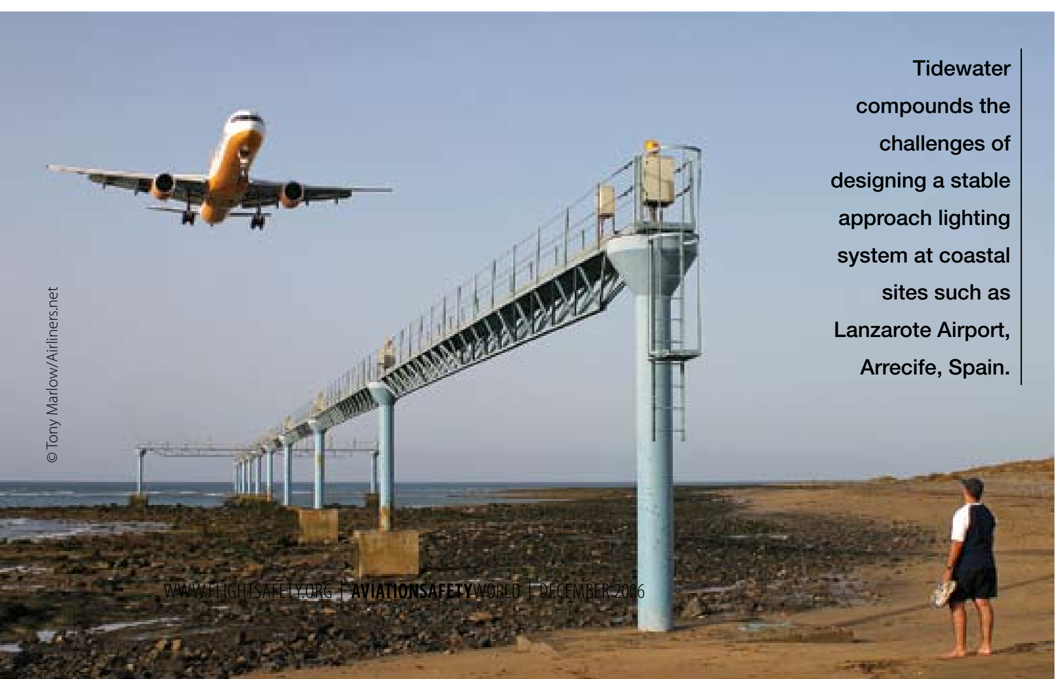
FAA's current standard equipment for Category III approaches is a dual-mode high-intensity approach lighting system with sequenced flashing lights model 2 (ALSF-2)/simplified short approach lighting system with runway-alignment indicator lights (SSALR), which enables air traffic controllers to operate the system in the energy-saving SSALR mode during Category I or II conditions. Today's ALSIP projects involve either total ALS replacement or a new installation, although a few salvaged components may be refurbished as spare parts for older ALS equipment still in service. "The cost for the complete replacement of a 2,400-ft long [732-m] medium-intensity approach lighting system with runway-alignment indicator lights (MALSR) starts at US$750,000 with the more complicated ALSF-2 starting at $1.5 million," Takemoto said.

FAA sometimes has attributed variation in ALSIP project completion to funding limitations and the nature of expenditures in the field. "The bulk of the costs involves construction to replace unreliable underground power cables and control lines, new foundations, [engine-powered] back-up generators and other infrastructure requirements based on local site conditions," Takemoto said. "A typical low-impact-resistant structure fiberglass pole with base plate mounting on break-away anchor bolts and light crossbar costs approximately $2,000 for the hardware. That would [total] $22,000 if all the MALSR support structures beyond 600 ft [183 m] from threshold were a nominal 20 ft [6 m] tall. If the terrain drops off, the hardware for [each of] the 40-ft [12 m] fiberglass poles can cost $4,500."

Ongoing research also addresses what NTSB has classified as FAA's "open acceptable response" to a safety recommendation left from the Little Rock investigation: that frangible ALS designs be developed as soon as technology allows for sites with exceptionally difficult design challenges, such as flood plains. "FAA design engineers consider the installation of fiberglass pole LIR structures in flood plains wherever practical," Takemoto said. "Several years ago, the ALSF-2 in Chattanooga, Tennessee, survived [except for some ground-level electronic equipment] when many of the fiberglass pole approach light supports were subjected to significant flooding. In the last two years, the FAA completed … 24 MALSR and eight ALSF-2 improvement projects [under ALSIP]. An additional nine MALSR and 11 ALSF-2 projects were completed [to establish new service]."

One clue to other near-term U.S. research is a $300,000 grant by the Airport Cooperative Research Program of the Transportation Research Board of the National Academies. The announcement said, "The [fiscal year 2007 ALS] research will explore and identify nonmetallic, all-composite construction with sufficient durability [for] sustainability, yet optimize frangibility through engineered fragmentation to specific energy forces; identify design options and possible solutions of an in-pavement automated de-energizing sensor/trigger to immediately cut all electrical power downstream when traversed by aircraft within the runway safety area; and equip [ALS] with [an] indicator pilot light for emergency responders to rapidly assess the power status of the system."

Also on the horizon are concepts for installing next-generation ALS flush with the ground. "The implementation of in-pavement ALS has great potential to improve runway safety," Takemoto said. "Future studies include the technical evaluation of light-emitting diodes for use on above-ground and inside-semi-flush approach lighting fixtures. Semi-flush approach lighting fixtures are very useful as airports extend their runways and move thresholds/runway ends closer to the perimeter of their property."●



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Tidewater compounds the challenges of designing a stable approach lighting system at coastal sites such as Lanzarote Airport, Arrecife, Spain.

Notes

1. Wiggenraad, Jaap F.M.; Zimcik, David G. "Frangibility of Approach Lighting Structures at Airports." National Aerospace Laboratory (NLR)–Netherlands. NLR-TP-2001-064, Feb. 13, 2001.
2. Zimcik, D.G.; Ensan, M. Nejad; Jenq, S.T.; Chao, M.C. "Finite Element Analysis Simulation of Airport Approach Lighting Towers." *Journal of Structural Engineering,* May 2004.