MANAGING AVIATION SAFETY: Selection of frangible composite structures for airports
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MANAGING AVIATION SAFETY:
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1. Introduction

When it comes to airport design, safety is one of the top concerns for consulting engineers, project engineers and airport operators. In general, the aviation industry has made great strides in safety, with aircraft accidents much less likely to occur today than 20 years ago. Although the number of aircraft in operation is constantly on the rise, accident rates are falling, making air transport the safest of all means of transportation.

Despite these gains in safety, the actual number of accidents will increase given the growing number of aircraft now in operation, even though the accident rate per flight may drop slightly. With aircraft carrying increasing numbers of passengers, the number of on-board fatalities per incident also has the potential to rise.

When creating or updating an airport design, one critical area to consider is the safety, maintainability and economics of support structures like approach lighting masts. These masts are governed by requirements of the United Nations’ International Civil Aviation Organization (ICAO) and the United States Department of Transportation’s Federal Aviation Administration (FAA).

Strict adherence to the ICAO and FAA rules is determined through the appropriate design, materials and testing for structures located within the “frangible zone” of 60 m to either side of the runway and approach line(s), including approach lighting masts, wind cone masts, anemometer masts, localizer supports, transmissometers, forward-scatter meters and fencing. As airport design consultants, engineers and authorities select these structures, it is important to fully explore their impact on flight safety, as well as their true compliance with FAA and ICAO standards as determined by a third party.

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2. Fatal accidents by flight phase and category

Fatal airline accidents can occur during any phase of flight, but most (57%) have occurred during the departure (take off / climb: 16%) phase and arrival (approach/ landing: 41%) phase, according to Boeing data (Fig. 1) [1]. During these phases, aircraft are close to the ground and in a more vulnerable configuration than during other flight phases. Also, the flight crew is dealing with a higher workload and reduced manoeuvring margins.

<table>
<thead>
<tr>
<th>Flight Phase</th>
<th>Fatal Accidents</th>
<th>Onboard Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi, load/ unload, parked, tow</td>
<td>11% 11% 5% 8% 9% 4% 11% 19% 23%</td>
<td>0% 12% 5% 11% 18% 3% 18% 17% 17%</td>
</tr>
</tbody>
</table>

Note: Percentages may not sum precisely due to numerical rounding.

In addition, runway excursion during take-off or landing, abnormal runway contact, and runway undershoot or overshoot combine to make the third most prevalent category of aviation fatality occurrences (Fig. 2) [1]. This and the previously noted accident statistics indicate how critical the inherent safety of airport support structures are, given their close proximity to the vulnerable take-off and landing phases.
Fatalities

No accidents were noted in the following principal categories:

- ADRM Aerodrome
- AMAN Abrupt Maneuver
- ATM Air Traffic Management/Communications, Navigation, Surveillance
- BIRD Bird
- CABIN Cabin Safety Events
- EVAC Evacuation
- F-POST Fire/Smoke (Post-Impact)
- GCOL Ground Collision
- ICE Ice
- LALT Low Altitude Operations
- LOC-G Loss of Control – Ground
- RI-A Runaway Incursion – Animal
- RI-VAP Runaway Incursion – Vehicle, Aircraft or Person
- SEC Security Related
- TURB Turbulence Encounter

For a complete description go to:
http://www.intlaviationstandards.org/

Note: Percentages may not sum precisely due to numerical rounding.
3. Frangibility and support structure standards

Frangibility is a major concern for airports, where various visual and non-visual aids are located near runways, taxiways and aprons. These structures include lighting towers, meteorological equipment and radio navigational aids, and they can pose significant hazards to aircraft in the event of accidental impact during landing, take-off or ground manoeuvring – some of the most vulnerable phases of flight.

ICAO and the FAA have stipulated rules on frangible airport support structures so that they are designed to break, yield on impact, and minimize damage to life and property. These rules owe their origin to a serious incident in 1971 where a Boeing 747 hit a portion of the approach lighting structure at San Francisco International Airport, critically injuring two passengers and significantly damaging the aircraft [2].

3.1 ICAO and FAA frangibility standards

Airfield consultants, project engineers and construction companies should consider the importance of frangibility when planning, designing and specifying new approach lines, or updating existing ones. Designing an approach line without verifiable frangibility aspects might lead into an outdated approach line that is unacceptable for flights from FAA- and ICAO-based airlines. This has the potential to limit airport safety, functionality and profitability.

The most current approach line reference material from ICAO is Aerodrome Design Manual Part 6 – Frangibility, First Edition – 2006 [3], superseding outdated [4-5] and incomplete [6-9] documents. For the FAA, the reference document is Advisory Circular 150/5345-5C, AAS-100, Federal Aviation Administration [10]. ICAO’s frangibility design requirements state the following:

All such equipment and their supports shall be frangible and mounted as low as possible to ensure that impact will not result in loss of control of the aircraft. This frangibility is achieved by use of light-weight materials and/or the introduction of break-away or failure mechanisms that enable the object to break, distort or yield under impact [3].

ICAO recommends dynamic tests for verifying the frangibility of navigational aids like approach lighting towers with an overall height greater than 1.2 m and located in positions where they are likely to be impacted by an aircraft in flight.

3.2 Frangibility design and testing

ICAO recommends dynamic tests for verifying the frangibility of navigational aids like approach lighting towers with an overall height greater than 1.2 m and located in positions where they are likely to be impacted by an aircraft in flight. When the height of a supporting structure exceeds 12 m, the frangibility requirement only applies to the top 12 m [3].

As relates to the frangibility of approach lighting towers, some of the more specific ICAO requirements are as follows. The FAA’s requirements are either exactly the same or closely resemble these:

• The support structure should not impose on the colliding aircraft a force in excess of 45 kN.
• The maximum energy needed to break the mast at the collision should not exceed 55 kJ.
• To allow the aircraft to pass, the failure mode of the support structure should be fracture, windowing or bending.
• The impacted structure should give way to passage of the aircraft in a manner such that the latter may still achieve a successful landing, take-off or missed approach.
• The light fitting and the supporting structure as a whole should be considered for establishing frangibility of the system. With regards to cabling, the designer should
ensure that there are points of disconnection so that segmentation is not hindered, if this is the intended mode of failure.

- Upon impact, the support structure may fragment into several components. The mass of these components should be as low as possible, and their manner of release should not cause a secondary hazard to the aircraft (e.g., to enter through the wind screen, fuselage, tail surfaces, etc.).

Support structures for wind direction indicators, transmissometers and forward-scatter meters should be tested for frangibility in accordance with procedures for approach lighting towers [3].

It is important that frangibility tests are conducted and verified under supervision of an independent third-party that is recognized by ICAO and the FAA, such as Intertek and NLR. It is also important that frangibility is verified for a range of mast heights and in a real-world configuration.
3.3 Support structure stability

In addition to its frangibility, a support structure must also be very stable, with minimal deflections allowed. Frangible safety masts must be able to withstand survival wind load and maintain stability in normal conditions at maximum wind speeds of up to 40 m/s. This wind speed requirement may be higher depending on local wind conditions (Fig. 4), particularly for areas with a frequent occurrence of strong winds or cyclones [11].

Both ICAO and the FAA stipulate the allowed deflection of approach lights as ±2° in the vertical axis and ±5° in the horizontal axis when the support is subjected to environmental loads. After the wind load, no permanent deformation of the structure is allowed [10].

Stability should also be a critical component of the testing process. As with frangibility testing, it is important to verify the stability of an approach lighting system for a range of different mast heights – for example, with a full load of five lights – to ensure it will perform as expected in an airport environment. While also assuring frangibility, the stability of tall support structures has strict allowed deflection tolerances for lighting, meteorological equipment and other navigational aids, and system suppliers insist on this requirement.
4. Materials selection for frangible structures

Any structure that is located 240 m from the end of the runway and within 60 m of either side of the center line of the runway and approach lines must be of low mass and frangible, per ICAO requirements [3]. When selecting frangible safety support structures, there are several important considerations, one of which is the materials used to make the mast. There are two primary materials used: glass reinforced plastic (GRP) and aluminium. Each exhibits different behavior in terms of safety, corrosiveness, radio frequency transparency and environmental impact. Carbon reinforced plastic (CRP) however, is likely to replace metals in long term providing unit combination of stability and frangibility in areas where frangibility criteria are not yet achievable.

4.1 Safety

Upon impact, a frangible structure should break into the smallest possible pieces so as to not cause injury or damage. Glass is brittle by nature, and the thin pull-wound wall tubes of glass reinforced plastic (GRP) composites have high bending stiffness and axial strength, making them optimal materials for the airport environment because they are strong yet collapse on impact [13]. When these thin – as thin as 2 mm in some cases – wall tubes are assembled into single poles or lattice structures, the frangible behavior becomes a built-in feature of the design so that the product does not require breakaway points [10].

On the other hand, aluminium requires breakaway points that may result in release of heavy components – perhaps up to 10-20 kg. These heavy mass components have the potential to become a secondary hazard to life and property.

4.2 Radio frequency transparency

The material chosen for support structures should not cause electromagnetic interference (EMI) or radio frequency interference (RFI) that could compromise the safety of aircraft communications systems. Aluminium is highly reflective and has the potential to disturb signals in the airport environment. GRP composite materials are transparent to radio waves and do not distort the instrument landing or communication systems [14].

Also, aluminium has high electrical conductivity, while GRP is a good isolator. This is an important factor when considering the safety of maintenance activities where aluminium may present a shock hazard.
4.3 Corrosion and environmental resistance

Frangible safety masts and their components should be fully resistant to environmental conditions. They should maintain their physical properties and resist corrosion through their expected lifecycle in temperatures ranging from 50°C to +80°C, as well as tolerate exposure to water, rain, humidity, maritime climate and ultraviolet radiation from the sun [11]. Such resiliency is important for safe operations of airlines operating in diverse global climates (Fig. 6).

Snow and ice cause extra stress for thermally conductive support structures like aluminium, which is a high heat transmitter. Aluminium also is subject to galvanic corrosion. As an alternative, glass reinforced plastic (GRP) is a low heat transmitter and does not freeze. It also does not corrode and tolerates chemicals used in the airport environment.

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4.4 Environmental impacts

Many airport and related organizations are concerned about ongoing environmental performance, especially as the public demands greater attention to sustainability. This concern extends to the materials used for approach lighting structures, which may require replacement over time. The manufacturing process for aluminum consumes high amounts of energy and produces greenhouse effects. GRP composites, on the other hand, have a low carbon footprint given their manufacturing process. They are also recyclable according to the EU Waste Framework Directive 2008/98/EC.

Fig. 6 - Koeppen's Climate Classification [15]
by FAO - SDRN - Agrometeorology Group - 1997

A) Tropical  B) Dry  C) Temperate  D) Cold  E) Polar

Fig. 6 [15] – Support structures should tolerate exposure to water, rain, humidity, maritime climate and ultraviolet radiation for a wide range of global climates.
5. Design considerations for frangible support structures in approach lines

Design is another critical consideration when selecting frangible structures for approach lines. For example, the height of the lighting tower plays an important role in approach lighting masts. Lighting towers can range to over 35 m in height, but frangibility is only required for the top 12 m of taller towers beyond 300 m from the landing threshold (Fig. 7). This is because masts exceeding 12 m can be fitted on a non-frangible footing [9] to maintain stability at higher wind loads.

5.1 Frangible behavior and testing

As a material, GRP is inherently breakable, but the issue of frangibility of GRP masts in an airport environment should be proven to meet ICAO and FAA standards through rigorous dynamic testing. This is especially critical when assessing pole versus lattice designs.

Both GRP pole and lattice masts can range up to 12 m, as ICAO and FAA limit frangibility requirements to the top 12 m. Therefore, frangibility should be proven throughout this height range.

When assessing the frangibility of pole versus lattice designs, it is important to consider that GRP pole designs cannot always remain both frangible and stable past 6 m in height, as calculations have proven. This is because extra reinforcement is required within the base of the pole wall for it to retain its stability past 6 m while carrying the appropriate load, with negative impacts on frangibility.

Also, the frangible behavior of GRP lattice masts are such that the mast breaks at the point of impact; even at lowest structural point, breakage is 10 cm above the base plate.
base to ensure pole stability, thus resulting in the structure breaking only at its weak points, leaving the possibility of larger heavy secondary profiles being released at impact.

Ultimately, potential buyers should verify that any support structure – whether using pole or lattice mast design – has been appropriately tested for frangibility. For structures not exceeding 1.2 m, ICAO allows static laboratory tests for verification of maximum breaking force. Breakable couplings are not allowed for installations with overall height exceeding 1.2 m.

For installations above 1.2 m, the requirement should be for verification through a full-scale dynamic impact test or computer analysis supported by a representative field test to ensure the structure withstands both a peak force of 45 KN and peak energy of 55 KJ [3]. These impact independent tests should be conducted throughout the entire structure for frangible compliance and not just at the top 50 cm only, as is currently required.

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In addition, masts should be tested with a load of one to six lights and cabling infrastructure to verify they are fully, 100% compliant with these ICAO and FAA frangibility standards. These results should be verified by a recognized and reputable third party like Intertek or NLR.

Fig. 8 - Third party given dynamic impact test
5.2 Stability

Stability is an important factor to consider when evaluating lighting structures, for example, especially for those with masts taller than 6 m with multiple lights. As mentioned previously, the allowed deflection of approach lights is ±2° in the vertical axis and ±5° in the horizontal axis when the support is subjected to environmental loads that include wind and ice, as stipulated by both ICAO and the FAA.

GRP pole masts work best at heights less than 6 m and carrying a light load, such as only one or two lights. If taller, the wall thickness of the pole must dramatically increase to maintain stability when lights are added, compromising frangibility compliance due to increased steel content.

For approach lighting with maximum light heights of 6 m and higher, GRP lattice masts offer a stable, yet lightweight and frangible, design that is strong under environmental loads. It is important, however, to have third-party verification that any lighting mast design, whether lattice or pole, can meet the ICAO and FAA vertical and horizontal deflection requirements under wind loads.

5.3 Installation, maintenance and safety

Just as airlines are concerned with the safety of the crew and passengers, so are airline authorities regarding the safety of the personnel who install and maintain frangible support structures. GRP mast design should support safe, yet cost effective, operations that minimize the need for maintenance personnel and expensive maintenance equipment.

When evaluating mast designs and suppliers, potential buyers should request to review installation and training manuals, as the quality of these support materials can vary considerably. Manuals should include informative drawings that illustrate the installation process, include mast layout designs for identification of placement positioning. Also, the supplier should offer on-site training for installation and maintenance.

For easier maintenance of lights, all GRP masts of 2 m and higher should tilt. GRP lattice masts over 5 m in height can be fitted with a counter-balanced center hinge assembly on the concrete base that allows one or two maintenance representatives to tilt the mast for service [13]. For extra tall structures of 35 m and higher, a counter-balanced steel post on a concrete base allows just one person to tilt the GRP lattice mast from ground level. Such lattice designs are not only safer; they also eliminate the need for winches, service platforms, or cranes for taller and heavier masts, as with extra tall pole masts.

In addition, buyers and evaluators should make sure that that light level is possible to extend or shorten on site by ±250 mm from the nominal height of the light, due to possible shifts in the ground level or in the foundation [13]. The color of the safety approach mast should be aviation yellow (ICAO) or aviation orange (FAA) and, for weather masts, orange/white or red/white [9].
In 2013, airline passenger numbers totaled 3.1 billion — surpassing the 3 billion mark for the first time ever, and that number is expected to grow to 3.3 billion in 2014 (equivalent to 44% of the world’s population) [16]. On average, more than 8 million people fly daily [16].

As flying passengers and airline traffic continue to increase, it is not surprising that safety rules and regulations continue to evolve and grow as well. The fragibility and performance of airline support structures are part of this growing safety evolution, and the materials, manufacturing technologies and design of fragible support structures have dramatically improved since the use of wooden pole or steel structures. In particular, GRP materials have been proven as one of the best materials for airport environments. The fragibility of any aid should always be proven before the aid is considered for installation. When evaluating approach lighting masts, meteorological equipment, radio navigational aids, or other fragible support struc-

5.4. Manufacturing and quality

The manufacturing process of fragible support structures should be monitored under an officially certified quality system, such as ISO 9001 or the equivalent. ISO 14 001 is also a desirable certification. With regard to manufacturing certifications, the most important question to ask is whether or not the certifying agency can audit the manufacturer at any time, as this is not the case with all manufacturers.

Another item to fully address is how the final qualification of a fragible support structure was performed. The final qualification of a design must be performed on a production quality unit [3], as in Fig. 9. It is therefore important to closely scrutinize the quality and extent of supplier’s dynamic impact tests, since, for example, the number of lights and height of masts has a significant impact on support structure fragibility behavior. In addition to this, each product should have been tested separately.

6. Conclusions

In 2013, airline passenger numbers totaled 3.1 billion — surpassing the 3 billion mark for the first time ever, and that number is expected to grow to 3.3 billion in 2014 (equivalent to 44% of the world’s population) [16]. On average, more than 8 million people fly daily [16].

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tures like fences, airport design consultants, engineers and authorities should look for a GRP design that is backed by rigorous frangibility and stability testing against ICAO and FAA requirements that is verified by a third party. This design should also provide for safe and cost-effective maintenance activities. In finding a supplier that offers advanced design, materials, and manufacturing processes to address these considerations, airports can enhance the overall safety and profitability of their operations.

7. References


[14] Comparative Properties of Fiber Reinforced and Filled Resin Matrix Composites

