Frangibility of approach lighting structures at airports

J.F.M. Wiggenraad and D.G. Zimcik
Frangibility of approach lighting structures at airports

J.F.M. Wiggenraad and D.G. Zimcik

This report is based on a contribution to the journal International Airport Review.

The contents of this report may be cited on condition that full credit is given to NLR and the author(s).
FRANGIBILITY OF APPROACH LIGHTING STRUCTURES AT AIRPORTS

J.F.M. Wiggenraad (National Aerospace Laboratory - The Netherlands, Head of the Structures Technology Department)
D. G. Zimcik (National Research Council Canada, Head of Aeroacoustics and Structural Dynamics Department)

1. INTRODUCTION

Aircraft operations at airports require the presence of various types of equipment, such as approach lights, wind direction indicators, instrument landing systems (ILS), or microwave landing systems (MLS). Some of these installations must be positioned close to the runways. Furthermore, these installations quite often need to be pointed in a specific direction within very narrow tolerances, even during severe weather circumstances. Therefore, their construction and their support must be stiff. However, should aircraft stray into these installations during landing or take-off, these same installations become obstacles to flight safety. Since the resistance of these "obstacles" may well determine the outcome of such a mishap, it must be minimal. In this respect, the damage which occurred in 1972, when a Boeing 747 made an incorrect take-off, and subsequently struck the approach lighting system, is described in reference 1. The aircraft lost two of its main landing gears, and parts of the approach light supporting structure had pierced the aircraft, endangering the flight safety considerably.
In order to reduce the threat to aircraft, the resistance of approach lighting structures should be minimized. Therefore, the equipment and its supports should be made "frangible". \textit{Frangibility} is defined as “the property which allows an object to break, distort or yield at a certain impact load while absorbing minimal energy, so as to present the minimum hazard to aircraft”.

The first investigations into the concept of frangible design of approach lighting structures were carried out in the US by the Federal Aviation Administration (FAA) (References 2-4), focused on industrial products used at airports. These structures consisted of hollow poles made of aluminium or glass/epoxy, aluminium truss structures and an aluminium tripod structure of an originally Swedish design. An effort to develop a frangible ILS glide-path mast was later reported in New Zealand (Ref. 5). Further information of these efforts are described in (Ref. 6).

The operational requirements for this equipment (i.e., stiffness and rigidity) and the desirable characteristics to minimize the threat to aircraft that might hit it (i.e., frangibility) are seemingly contradictory. Accordingly, the International Civil Aviation Organization (ICAO) initiated the "Frangible Aids Study Group" (FASG), in 1981. Members of the FASG are Canada, the Netherlands, Sweden, the United Kingdom (on behalf of the ACI) and the United States, although Germany and New Zealand also participated in the initial stages. The task of the FASG is to define the design requirements and to develop guidelines for frangibility for these types of equipment. The present article gives an overview of the main steps in this development, and of the current status.
2. EXPERIMENTS

To date, the FASG has focused on the problem of aircraft impacting obstacles when taxiing, and of aircraft impacting approach lighting structures on take-off or landing. As a minimum requirement, it was defined that a small commuter aircraft of 3000 kg, impacting the approach lighting structure at 140 km/h during landing or take-off, should be able to continue safely. Although approach lighting towers may be of any height, only the top 12 meters of the structure was deemed to be frangible. Frangibility should be demonstrated by considering an impact at a position of 2 m below the top of the structure. The mass located at the top of the structure which may include lights, a cross bar when present or other instruments as well as the presence of electricity cables should be taken into account to demonstrate frangibility.

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. Moreover, full scale impact tests similar to the tests performed by the FAA in the seventies, were thought to be required to demonstrate whether an approach lighting structure could be considered frangible. In such tests, structures should be impacted at 140 km/h by a light wing section representative of a 3000 kg aircraft. The damage to the wing, and in particular the survival of the front spar, would indicate whether an impact could be judged as "acceptable", i.e., whether the design of the approach lighting structure could be considered "frangible".
At the start of the FASG investigation, the insight into the physics of such a dynamic event, i.e., of the impact of a flexible wing section on a flexible approach light structure, was poor. The results of full-scale experiments, performed earlier by the FAA, showed that some of these designs could be considered as adequately frangible, based on the failure mode of the approach light structure and, in some cases, the damage to a wing. However, most of these full-scale tests were carried out without instrumentation, and with rigid impactors such as steel bars rather than wing sections. Hence, they did not produce suitable data for the definition of criteria for frangibility, with respect to the parameters "peak force", "energy" and "impact duration".

Subsequently, several full-scale experiments have been carried out on five different structural designs, in accordance with the FASG recommendations, i.e., consisting of the full scale impact at 140 km/h with an appropriate wing section, with a top mass and electric cables present. In addition to these recommended conditions, certain variations were also considered. These included reduced impact velocity, differing impactors including a large diameter rigid impactor and/or a lighter wing section: and the absence of a top mass and/or electric cables. These five designs tested encompassed aluminium tripods (Refs. 7-8), shown in Fig. 1, a frame of glass/epoxy poles (Ref. 9), shown in Fig. 2 and lattice structures made of glass/epoxy (Refs. 10-11) shown in Fig. 3, or of aluminium (Refs. 12-15), shown in Figs. 4 and 5.

At the FASG-meeting in 1998, the test data from these programmes were analyzed and graphically presented to show the impact energy versus the peak force. Later, additional test results from tests with simulated masses of various values obtained in Canada (Refs. 13-15) were added. This graph, see Fig. 6, includes all data, including results obtained for
impact conditions using a large diameter rigid impactor. All four commercial products (Refs. 7-8, 10-15) were shown to be acceptable, based on the analysis of the resulting damage to the wing section. The test of a rather heavy design (Ref. 9), intended to carry five non-standard lights of significantly larger diameter and mass, was judged not frangible under this recommended specification for light aircraft. The impact characteristics for those structures deemed as meeting the above frangibility requirement for light aircraft based on these impact tests are bounded by an impact energy of 55kNm, and a peak force of 45 kN. These values for maximum impact energy and peak force are being proposed as requirements for frangibility of such structures. Moreover, since the results show that testing with a large diameter rigid impactor such as a steel bar will lead to higher values for the peak force, it is thought that future tests can be carried out with a rigid impactor to save costs. However, the presence of an equivalent top mass to represent the lights and a cross bar, and the presence of electric cables must be taken into account, as an omission of these critical items may lead to nonconservative results. The parameter "impact duration" was considered less important, as this is determined by the geometry of the mast and the impact velocity. The requirement that an approach lighting structure should not wrap around the wing section nor puncture an adjacent part of the aircraft is more significant in this respect. However, all these recommendations have yet to be accepted by ICAO.

3. NUMERICAL ANALYSIS

It would be of great advantage, if frangibility could be validated by numerical analysis. Given the results obtained today with specialized computer codes simulating crashing
aircraft, such an approach has become feasible. Presently, the frangibility of an approach lighting structure can only be shown with sufficient confidence by performing the full-scale test on representative structures as described above. Such experiments are expensive to perform, and can only show frangibility for the unique set of experimental and loading conditions specified, due to the cost of such experiments. Numerical simulation with analytical codes is becoming more acceptable, however, with access to more powerful computers and proven commercial codes. Nevertheless, the confidence in numerical solutions for entirely new structural concepts is still limited, which requires that the results need to be validated experimentally. However, analytical and numerical codes, which are validated through comparison with test data obtained even over a limited range of parameters could be used to assess the full range of parameters, including speed, direction and height. Also, such a technique can be used to evaluate the performance of new designs of towers or new aircraft or flight configurations, in order to at least enable the designers to "get it right" the first time, given the high cost of testing. The availability of a reliable computer code is also beneficial to the airworthiness authorities, who are to judge the frangibility of scaled versions of a previously certified design. Finally, the use of a numerical method may be the only approach to judge the frangibility of larger structures, such as ILS glide path masts.

Currently, the development of numerical simulations is being carried out at the National Aerospace Laboratory (NLR) in the Netherlands with support from Twente University and at the National Research Council Canada (NRCC) in Canada. The NLR approach is to use a pc-based code, developed since the seventies for the assessment of the
crashworthiness of general aviation airplanes and helicopters, that has become a standard tool for most of the helicopter industry (Ref. 16-17). The model for this code simplifies the wing section and the approach lighting structure by mass points and non-linear beams. The input for the non-linear beams must be determined on the basis of laboratory tests on components, for which reason the code is described as a hybrid finite element code. The disadvantage of this method is the need for component testing, but this is often part of the development process of a structure anyway. The advantage is the quick turn-around time of the computation, because of the small size of the model (typically 100 masses and 200 beams) and the confidence in the modelling at the level of components.

A typical example of the results of this analysis method for a fibreglass/epoxy lattice structure is shown in figure 7.

The approach followed by NRCC in Canada is based on a finite element analysis (FEA) code (Ref. 18), where the properties of the wing and approach lighting structures are defined at the material level. The FEA method is one of the most succesful numerical methods for structural analysis. This approach can provide detailed modelling of the local and global deformation of the tower under transient dynamic loading. Three-dimensional models to account for edge effects and local deformation allow detailed assessment of damage and the prediction and identification of true modes of deformation during the impact. The failure mode of any tower may vary, based on the range of parameters considered, and significantly different results can be obtained for impact force and energy to failure.
A discrete model to simulate the impact of the tower was developed using a non-linear transient solution (Ref. 17). The tower material was modelled as aluminum with elastic-plastic properties and three impact speeds (50, 80 and 140 km/h) were used to compare to the experimental results. A number of simulations were completed to investigate a range of test parameters measured, including impact speed and impact direction. In addition, the tower dynamic behaviour (failure mode) was compared to the visual data obtained from the high speed video.

Results of the simulation compared very well to the measured test data for both the numerical values of energy and peak force as well as the mode of deformation. The deformation of the tower during the test is shown in Fig. 8a and is compared with the predicted response of the tower model in Fig. 8b, for impact at a speed of 140 km/hr. Comparison of the observed and the computed deformation mode, can be seen to be very good, thereby providing confidence in the modelling approach and demonstrating the efficiency in use of numerical simulation. Similar simulation results have also been obtained for other tower designs described above, including shell type structures as well as the lattice type design described here.

4. CONCLUSIONS

The present article has given an overview of the development of design requirements and guidelines for frangible approach lighting structures. Currently, experimental data has been accumulated, in order to propose criteria for frangibility to ICAO for consideration for approval by member states. These criteria propose limits on the peak force and
absorbed energy which occur during an impact of the structure by a wing section of a small 3000 kg aircraft at a velocity of 140 km/h. Validation of performance to these criteria by any structure must still be shown by a full scale impact test at this velocity. However, work aimed at the development of the capability to determine the required frangibility by numerical analysis has provided promising initial results for further consideration.

5. ACKNOWLEDGEMENT

The funding of the aviation authorities FAA, RLD (Mr. Ton Franssen), Transport Canada (Mr. Mahmoud Farha) and LFV (Mr. Goran Eriksson) has been very important to develop the understanding and implication of the design and requirements for frangible approach lights. In addition, the participation and financial efforts provided by several manufactures of approach light structures must be acknowledged.

6. REFERENCES

1. NTSB Aircraft Accident Report, NTSB-AAR-72-17, 1972.


Fig. 1  Impact test on aluminium tripod (Ref. 8)

Fig. 2  Frame of glass-epoxy poles (Ref. 9)
Fig. 3  Impact on glass-epoxy lattice structure (Refs. 10-11)

Fig. 4  Impact on aluminium lattice structure (Ref. 12)
Fig. 5 Experimental set-up of impact test on aluminium lattice structure (Refs. 13-15)
Fig. 6  Overview of test results for impacts on approach lighting structures
Fig. 7a  Failure mode prediction versus result at 0.07 sec

Fig. 7b  Impact energy prediction versus test results
Fig. 8a  Video recording of the deformation of the tower (140 km/h) (Ref. 15)

Fig. 8b  FEA prediction of the deformation of the tower (140 km/h) (Ref. 17)