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Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

The following analysis confirms the frangability of the FUCHS Europoles GFK GmbH Approach Lighting poles according to ICAO Aerodrome Design Manual Part 6.
The National Aerospace Laboratory NLR was commissioned to carry out this analysis in 2003.

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Summary

The frangibility of Pfleiderer's approach light mast has been estimated by means of numerical analysis. The numerical analysis was carried out with two computer codes: KRASH and PAMCRASH. The numerical simulation focused on the scenario as specified by ICAO's Annex 14, and corresponds to the scenario of test programmes carried out for other frangible approach light masts. The failure mode predicted by the PAMCRASH analysis is likely to be the failure mode that will occur in a physical experiment: the impactor cuts right through the mast. Both analyses produced acceptable values for the force-time history, and hence the absorbed energy, and the peak force. The numerical results therefore indicate that the mast by Pfleiderer may behave frangible, when tested in a full-scale physical experiment. The fact that the structural mass of the Pfleiderer mast is comparable to the mass of other masts that were shown to be frangible in full-scale impact tests, is a further indication of the frangibility of the Pfleiderer mast.

Contents

(14 pages in total)

1 Introduction

1.1 Frangibility of airport obstacles

Certain types of equipment, such as approach lights, wind direction indicators, microwave landing systems and instrument landing systems, need to be positioned close to runways at airports because of operational requirements. Some of these systems require narrow tolerances with respect to position and orientation. Therefore the supporting structures must be stiff enough to perform with these tolerances, even in bad weather conditions and jet stream from aircraft. However, positioning them near runways makes these constructions potentially hazardous to aircraft in trouble. When an accident occurs, the impact resistance of these structures must be minimal. Therefore the supporting structures must be of a frangible nature, in order to reduce the risk of damage to aircraft in case of emergencies. According to FASG Annex 14 (Ref. 1) the definition of frangibility is:

"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 minimum hazard to aircraft"

With respect to frangible structures the following problems arise:

- Manufacturers do not know how to design for a dynamic load case of two very strongly deforming bodies.
- Authorities do not know how to judge frangibility of structures proposed.

To address these problems the *'International Civil Aviation Organisation (ICAO)'* initiated in 1981 the *'Frangible Aids Study Group (FASG)'*. The task of the FASG is to develop design requirements and guidelines for these types of frangible structures. From the outset the following design criterion was defined:

- A light aircraft (up to 3000 [kg]) should be safe when impacting an approach light structure at a speed of 140 [km/h].

The FASG so far has come to the conclusion that the frangibility of approach light masts should be established by performing a full-scale test. The test should be performed by impacting a representative wing-section with a velocity of 140 [km/h] against a ± 6 [m] tall mast. The impact point should be approximately 1.5 [m] below the top. The mass of the lights including the crossbar should be placed on top of the tower. The amount of damage to the wing section then indicates whether a mast design is appropriate or not.

From the experience obtained during testing several approach light masts it was concluded by the FASG that a structure can be considered frangible when the impact energy is limited to 55 [kNm] and the peak force does not exceed 45 [kNm]. These values where derived from a range of full-scale impact tests such as done by EXEL (Finland) (Ref. 2) and MILLARD (Canada) (Refs. 3 and 4).

Nowadays, with the state-of-the-art software codes, it is believed that frangibility of a design for an approach light structure can be predicted by numerical analysis. The present report provides the (first) numerical analysis of the frangibility of a tubular composite approach light mast as manufactured by Pfleiderer.

1.2 Numerical analysis tools for impact problems

Several numerical analysis tools are available for solving the mathematical models that correspond to the physical process of impact. A popular and widely applicable numerical analysis method is the finite element method. The method relies on a discretisation of the analysis domain in simple elements (for example triangular elements or line elements). Several commercial finite element codes are available. Among others, NLR has two of these codes available for the simulation of impact problems:

- DRI/KRASH
- ESI/PAMCRASH

Both of these codes have successfully been applied to impact problems concerning lattice approach light masts (e.g. Ref. 5). Without going into details two crucial differences between KRASH and PAMCRASH are outlined.

The first is the way in which material properties and failure criteria are taken into account. In a general-purpose finite element code like PAMCRASH all material data and failure criteria are provided on *element* level. This implies that detailed information has to be available on material level. These material properties can be determined by tests on *coupon*s, which in general do not coincide with any structural component. KRASH however supports the possibility to model on *component* level. This means that results of tests on structural *components* can be used as input. This can be a benefit because some uncertainties in material behaviour under complicated dynamic loads can be eliminated.

The second is the availability of features to accurately model a structure. KRASH only supports line elements (beam elements) for the actual discretisation of the structure. While this is no problem for lattice structures, this might not be true for structures representing a ‘single cell’ structure like the tubular approach light mast manufactured by Pfleiderer. PAMCRASH supports a wide variety of elements ranging from line elements to solids.

The criterion for selecting the most appropriate code for the simulation of an impact problem is determined by the availability of test data. If test data is available on component level KRASH probably is suitable. Also in cases where component test data is available for similar components, KRASH can be a good option. However, if no component test data is available, an accurate representation of the structure and especially the impact zone is necessary. In those cases, PAMCRASH offers more accuracy and flexibility than KRASH.

1.3 Report outline

This report presents the results for the numerical simulation of an approach light mast manufactured by Pfleiderer. Based on the arguments of section 1.2 PAMCRASH seems to be the most suitable program in the current situation. However, to have some data for comparison, it was decided to analyse the pole with both PAMCRASH and DRI/KRASH. Different parameters were used in the analysis to take into account effects of different top masses and variations in failure stresses. Chapter 2 lists all the structural and material data provided by Pfleiderer. Chapters 3 and 4 describe the analysis models and results for both DRI/KRASH and PAMCRASH. Finally, in chapter 5 the results of the analysis are presented with respect to the frangibility criteria.

Fig 1.1 Composite approach light mast manufactured by PFLEIDERER Aktiengesellschaft

2 Structural and material data provided by Pfleiderer

2.1 Structural Data

The pole under consideration is a tubular mast of 10 [m] length. The top and bottom outside diameters are 0.168 [m] and 0.330 [m] respectively, while the top and bottom wall thicknesses are 0.005 [m] and 0.008 [m]. At the bottom the pole is connected to a concrete block. This concrete block is far heavier and far more rigid than the mast itself. A crossbar that holds the approach lights itself is located at the top of the mast (Fig. 1.1).

2.2 Material data

The mast is made of a composite material of polyester (matrix) and glass-fibres. Relevant material data provided by Pfleiderer are listed in table 1.

Table 2.1 Material Data

E-modulus		
along pole	18	GPa
circumferential	9	GPa
Failure Stress		
tension	220	MPa
shear	50	MPa
Density	~1600	kg/m^3

3 DRI/KRASH

3.1 Modelling

Mast

The mast consists of beam elements connected to mass points (Fig. 3.1). Each element has geometric, material and failure data associated to it.

The geometric and material data follow directly from the dimensions of the mast and table 2.1. DRI/KRASH calculates internal beam forces and moments. It is assumed that the beam fails if one of the internal beam forces or moments exceeds the corresponding rupture value. The rupture forces and bending moments used in the model are derived from the maximum stress level and the local cross-sectional area and stiffness. For example, the rupture force in axial direction is calculated as follows:

$$f_{axial,\max} = A_{local}\sigma_{\max} \tag{3.1}$$

Impactor

The impactor is also modelled with beam elements and mass points. The total mass of the impactor is 3000 [kg] and the impact velocity is 140 [km/h].

3.2 Results

Figure 3.2 shows the result of the impact at several time intervals. The corresponding maximum impact force and the accumulated energy during the impact process are 18 [kN] and 22 [kNm] respectively. It is observed that the pole does not fail in the impact region, but at the second node of the first element at the bottom.

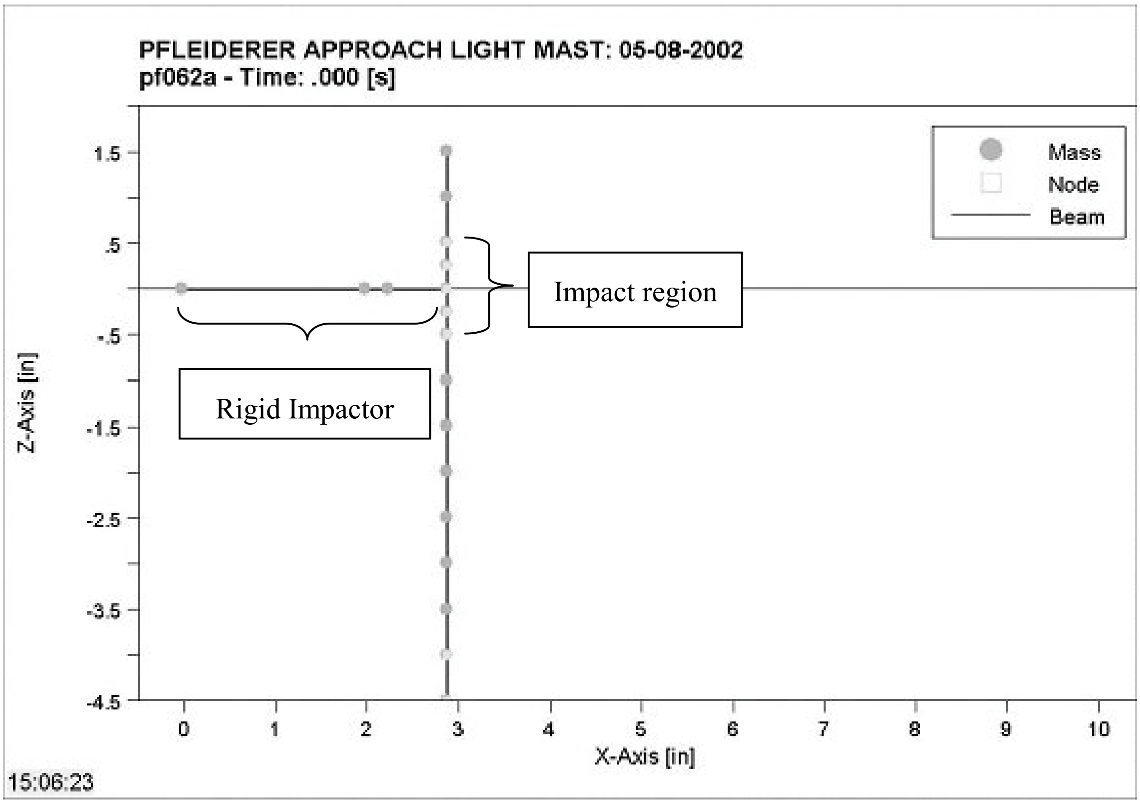

Fig. 3.1 KRASH Analysis model. The mesh in the impacted region is refined

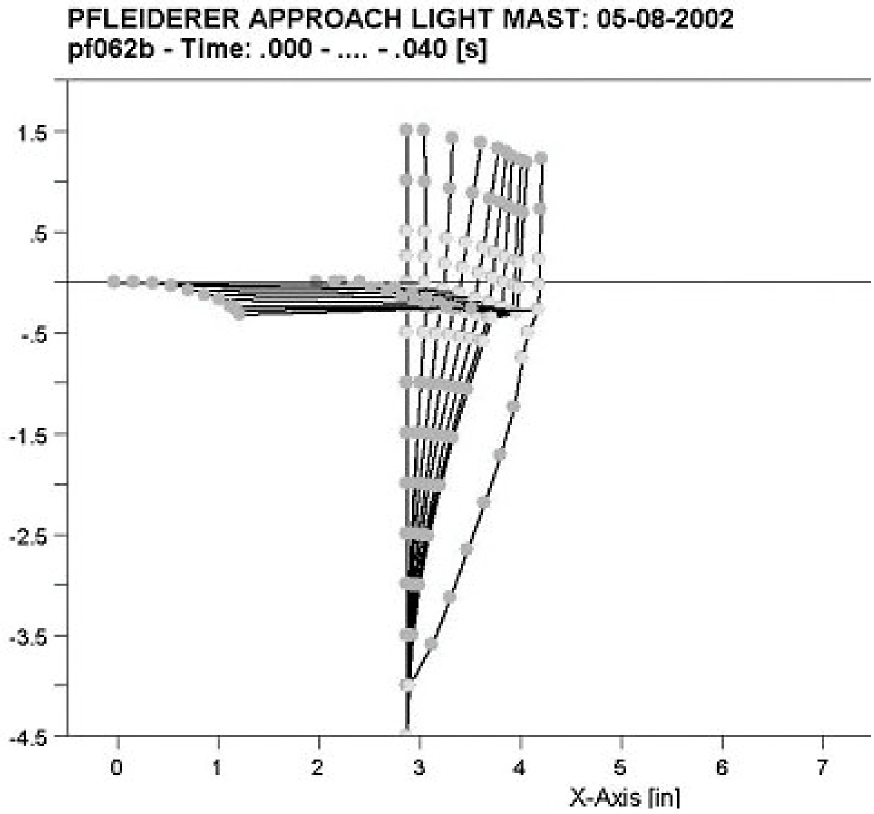

Fig. 3.2 Deformation of the pole at several time intervals up to the point of failure

4 PAMCRASH

4.1 Modelling

The analysis has been carried out with PAMCRASH Version 2001 (Ref. 6) The pole and wing were modelled in MSC/Patran and transferred to a MSC/Nastran bulk data deck. This bulk data deck is imported in the pre-processor *GENERIS* for further processing. It is important to select for the pole, wing and top section of the pole different (dummy) material properties in Patran. This eases the selection and definition of material properties in PAMCRASH significantly. It is also beneficial to place the wing as close as possible to the pole in order to reduce the time to first contact, and hence to reduce the calculation time.
The maximum analysis time is set to 0.01 seconds (10 ms). Since the wing has a speed of 140 km/h, within this time the wing has travelled through the pole. This time frame is sufficient for the current investigation as the top section is completely separated, according to the analysis.

The wing is modelled as a rigid impactor (undeformable) using shell elements. The thickness of the shell is 0.1 m. The specific weight of the wing material is set to 15040 kg/m^3 in order to have a wing mass of 3000 kg. The modulus of elasticity of the wing is set to a (dummy) value of 200 GPa. The wing has an initial velocity of 140 km/h or 38.89 m/s.

For the pole a multi-layered shell element (material type 130) has been defined. The pole is fixed at the bottom.

To simulate the concentrated mass on top, the top of the pole has been modelled as a linear elastic thin shell with material type 101. It is given a (dummy) elastic modulus of 200 GPa. The density of the material is 780 kg/m^3 to represent the concentrated mass of 15 kg.

Contact between pole and wing is defined as node to segment contact (contact type 34). To reduce calculation time, only part of the pole is selected for contact detection. Also, only the front part of the wing is selected to participate in contact. If longer impact times were to be considered (e.g. to determine if the pole hits the wing at the end), a larger part of the pole and the wing should be included as well (not in the present analysis).

4.2 Material and damage properties used

The selected material type is a multi-layer shell material (material type 130). Although no lay-up details of the actual material are available, definition of a multi-layer shell material is necessary for the accurate representation of orthotropy.

Each individual layer consists of materials modelled as elastic damaging fibre-matrix (bi-phase or global) composite material. Plies are numbered consecutively from shell element side z = -t/2 to z = +t/2 where t is the element thickness. Each specific ply corresponds to one integration point across the thickness of the shell, located at the centre of the ply. The ply material model used is a bi-phase ply model. Data for the matrix, the fibres and the damage behaviour must be given (see App. A).

The material coordinate system of orthotropy is defined such that 1-axis of orthotropy coincides with the fibre direction, the 2-axis is perpendicular to 1 within the plane of a uni-directional ply, and the 3-axis is normal to the plane of the ply. The material parameters are defined with respect to the natural coordinates of orthotropy.

Several runs were made with varying parameters. The most realistic run was 73b. For the glass fibre following material properties are known:

E_{11} = 18 GPa
E_{22} = 9 GPa

σ_b = 220 MPa
τ_b = 50 MPa

Assuming a uni-directional ply material, the fibre and matrix material properties can be estimated. Using a fibre fraction of 0.57 results in the fibre modulus of elasticity E_f = 28.0 GPa and the matrix modulus of elasticity E_m = 10.0 GPa in tension (see Appendix A). For compression the values have been reduced to 25 GPa and 8 GPa respectively, which are estimated values. The shear modulus was taken as G = ~3.5 GPa for the matrix material (in both tension and compression). Damage values were also estimated.

4.3 Results and discussion

Figure 4.1 shows the failure of the pole at the point of impact at three different time intervals. It is observed that the failure mode is brittle. In figure 4.2 and figure 4.3 the time history of the contact force and internal energy are shown. The maximum contact force is 51 kN , which occurs at t = 3.2 msec. The internal energy at the end of the analysis time (10 msec) is 2000 Nm.

The peak forces calculated in the different runs are close to the critical region (45 kN). So it is very important to have the correct material and damage properties for the glass fibre material. The energy levels are much lower than the allowed value (55 kNm). This is caused by the low moduli of elasticity of the glass fibre material resulting in brittle material behaviour, i.e. the material does not absorb much energy but fails in the early stage of the impact.

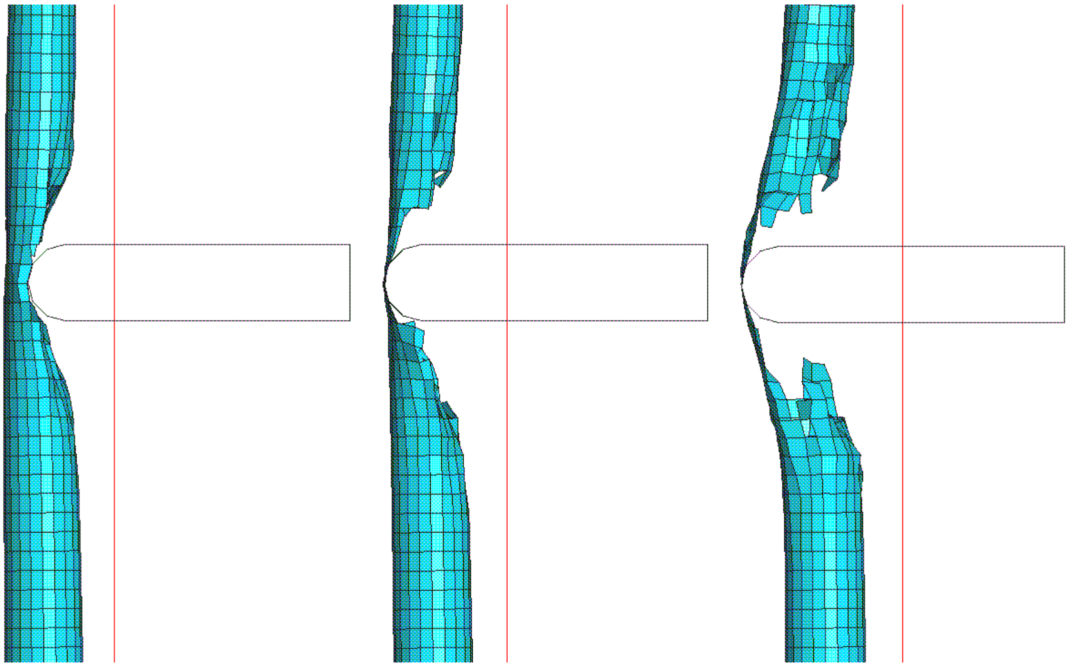

Fig. 4.1 Pole deformation at t = 0.005, 0.0074 and 0.01 seconds

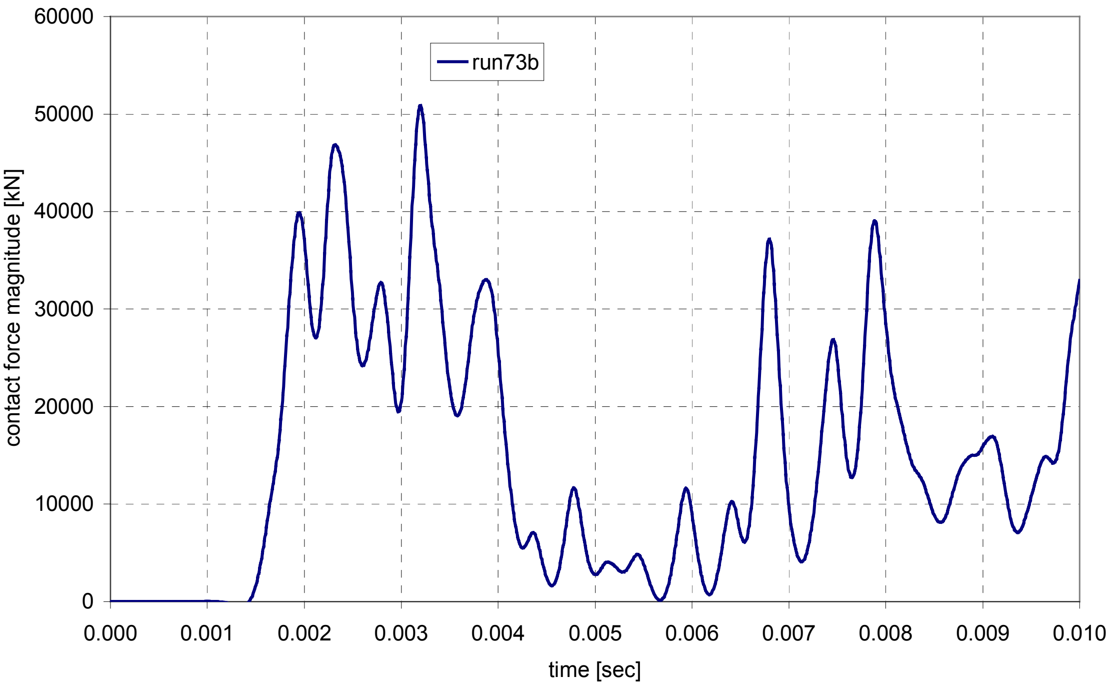

Fig. 4.2 Contact force time history

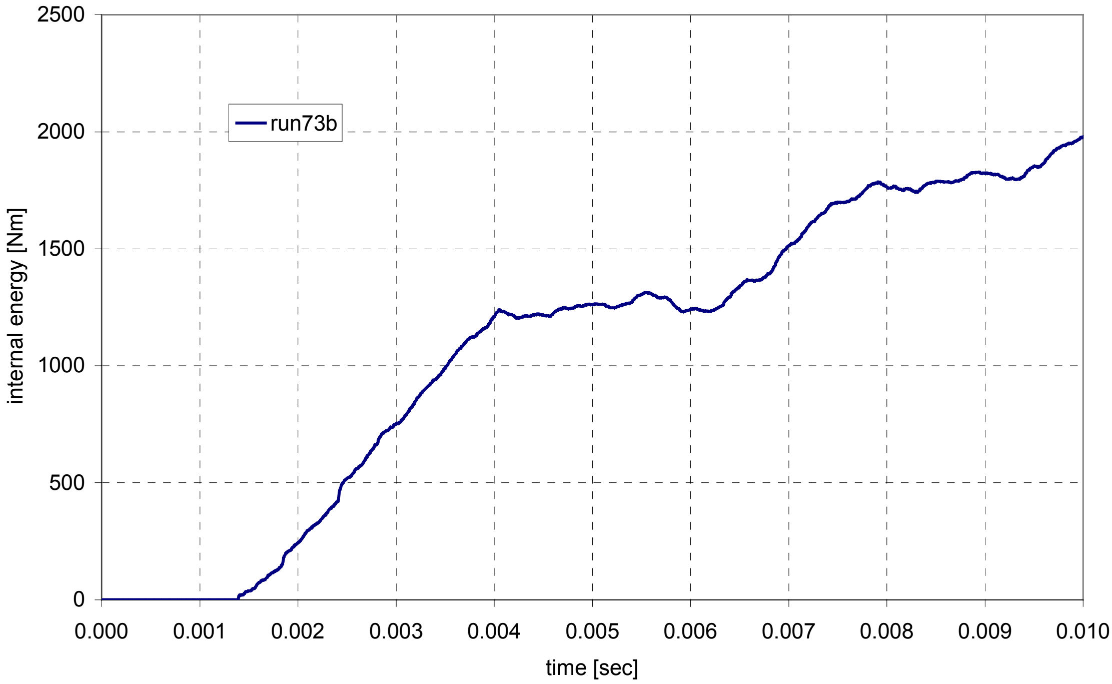

Fig. 4.3 Internal energy time history

5 Conclusions

The frangibility of Pfleiderer's approach light mast has been estimated by means of numerical analysis. The configuration of the mast is a tubular pole, made of glass/polyester composite material. The material is lightweight, with a specific mass of 1600 kg/m³. The fibres are short fibres, stitched onto a woven roving. The wall diameter of the tube varies from 330 [mm] to 168 [mm], while the wall thickness varies from 8 [mm] to 5 [mm].

The numerical analysis was carried out with two computer codes: KRASH and PAMCRASH. With the first code, the mast is represented as a rough model with large "structural" elements. With the second code, the mast is represented with a more refined model with smaller "material" elements. The input data for the models was generated on the basis of information provided by Pfleiderer: no physical tests were performed to generate any data.

The numerical simulation focused on the scenario as specified by ICAO's Annex 14, and corresponds to the scenario of test programs carried out for other frangible approach light masts. The mast was clamped at the bottom, and hit by a rigid impactor 1.5 meter below the top, at a velocity of 140 km/h. The mast contained a concentrated mass of 15 kg on top, to represent a cross bar with lights.

The KRASH-analysis and the PAMCRASH-analysis produced different failure modes. The failure mode predicted by the PAMCRASH analysis is likely to be the failure mode that will occur in a physical experiment: the nose of the impactor cuts right through the mast. Hence, the impact is of a short duration, corresponding to the time that the impactor passes through the cross section of the mast: a few milliseconds. The KRASH analysis predicts the top section to travel with the impactor, which is unlikely, because of the inertia of the concentrated mass on top of the mast.

Both analyses produced acceptable values for the force-time history, limiting the absorbed energy to 22 kNm (KRASH), or ~2 kNm (PAMCRASH). The PAMCRASH-value is much smaller than the allowable value of 55 kNm, as specified tentatively by the Frangible Aids Study Group (FASG) of ICAO, mainly because of the short duration of the impact. Also, the predicted peak force occurring during the impact event is smaller or approximately equal to the specified maximum force of 45 kN as tentatively specified by the FASG: 18 kN (KRASH), or 51 kN (PAMCRASH).

The numerical results therefore indicate that the mast by Pfleiderer is expected to behave frangible, when tested in a full-scale physical experiment. The main parameter in the impact event is the mass of the mast, per linear meter. The structural mass of the Pfleiderer mast at the point of impact (4.7 kg/m) is comparable to the mass of other masts that were tested successfully before (3.8 kg/m, Ref. 5). Therefore, it is estimated that the Pfleiderer mast is frangible, although this conclusion is based on numerical simulation alone.

6 References

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