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A Preliminary Model to Simulate the Impact of a Frangible Approach Light Structure by an Aircraft Wing Section

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Abstract - Certain types of equipment, such as approach light masts and antennas, need to be positioned close to runways at airports because of operational requirements. The supporting structures of such equipment must be of a "frangible" nature, in order to reduce the risks to aircraft in case of emergencies. The design and qualification of frangible support structures is difficult, due to the impact dynamics involved. In the feasibility study presented here, the suitability of the hybrid DRI/KRASH code to address this problem was investigated, by simulating the impact of a wing section on a frangible approach light structure. DRI/KRASH simulations were compared with experimental results. The impacts were shown to be simulated well with DRI/KRASH. The overall force of the impactor as well as the overall strain energy computed during the simulations is in good correspondence with the experimentally determined values. The research will be continued by refining the analytical model, from a 2-dimensional representation to a 3-dimensional representation and by incorporating failure criteria obtained with detail tests on mast components.

INTRODUCTION

Certain types of equipment, such as approach light masts and ILSS antennas, need to be positioned close to runways at airports because of operational requirements. However, in case of emergencies during take-off or landing, they become obstacles to aircraft safety. Hence, the requirements for the design of such structures are stringent and seem contradictory: they need to be stiff during operation, and collapse easily during an impact by an aircraft. Such a property is known as "frangible". The design of frangible structures is not easy, because of the impact dynamics involved. Designers tend to consider the problem as a quasi-static case. The aviation authorities, on the other hand, have difficulty in evaluating the frangibility of structures proposed for installation at airports, and are presently in the process of defining requirements and specifications. For the case of approach light structures, full scale testing by impacting light aircraft wing sections at a speed of 140 km/h is currently the approach to demonstrate the frangibility of a design.

In order to support the designer as well as the certifying authorities or their consultants, a computer code is being developed to predict the global behaviour of new approach light designs when hit by the wing of a small aircraft at relevant speeds. This computer code, DRI/KRASH, is already available to analyze the crashing of aircraft and helicopters. The aircraft model is built up of non-linear beams to represent the stiffness of the structure, mass points to represent the inertia, and energy absorbing springs to represent the crushing part of the structure. The characteristics of the springs can be programmed according to test results obtained with component tests. The latest version of DRI/KRASH contains an option which allows for specifying different initial velocities for each of the individual masses. This feature, along with many other improvements, extends the capability of the program to model coupled interaction between a moving mass system (aircraft) and a stationary structural system (approach light structure).

In this paper the results of a feasibility phase are presented. A comparison is made of the numerical results obtained with a preliminary model with full scale test results generated with the commercially available frangible approach light structure of EXEL. The paper is concluded with a short survey of the continuation of the work, i.e., the further development of the model, and the generation of additional test data.

RESEARCH PROGRAMME

A research programme was defined by the NLR with the object to develop and validate the DRI/KRASH code up to a level where the frangibility of structures at airports can be evaluated. The programme consists of four phases:

- A feasibility phase.
- A development phase.
- A validation phase.
- A phase in which design criteria are generated.

During the feasibility phase the merits and possibilities of the development of the DRI/KRASH code will be evaluated. Existing full scale impact test results on a proven frangible approach light structure made of glass/polyester by the Finish company EXEL is being used to guide this development.

During the development phase, the input model of the EXEL mast will be upgraded. The numerical analysis will predict not only the overall failure mode, but also the correct response in terms of impact force, impact duration and energy consumed.

During the validation phase an aluminum Canadian mast design will be used to ensure that the code can simulate the behaviour of structures other than the EXEL mast as well. Of the latter mast, full scale test results are available of impact tests under different velocities. This analysis must demonstrate the reliability of the DRI/KRASH code to simulate impacts under different velocities.

During the final "design criteria" phase, the code will be used to formulate general design guidelines for the design of frangible structures.

FULL SCALE EXPERIMENTS

Six impact tests were performed by EXEL in 1991, three baseline tests on masts without a cable and three tests on masts with a lighting cable, reference 1. The impacts were performed by a wing section attached to a high speed struck. The mast and the test set-up are shown in Figure 1. The composite EXEL masts had the following dimensions and features:

- Composite lattice structure (glassfibre/polyester) consisting of 4 vertical tubes and diagonal cross members.
- Square cross section of 400 * 400 mm.
- 6 meters in height.
- A top mass of 15 kg to simulate a cross bar with three lights.
- Vertical tubes ϕ 32/28 and diagonal tubes ϕ 22/18.

The masts were impacted under the following conditions:

- Impact speed of 140 $^{km}/_{h}$.
- Impact height of 4.1 m.

The following parameters were measured (average values of the baseline tests 1-3, without cable):

- A contact time of 0.1 sec.
- An impact energy of 36.4 kNm.
- A peak force of 25900 N.
- A mean contact force level of 9430 N.

All masts broke into two main sections at about 1 to 3 meters above the ground. The masts broke also into several smaller sections and into separate parts (=diagonals), see figure 2. The 15 kg weight at the top of the mast, simulating a cross bar with three lights, always dropped within 2 or 3 meters from the base plate. During each test, the mast penetrated the leading edge skin panels up to the front spar (about 340 mm). The inner load carrying structure of the wing section (front spar) remained intact. Photographs of nine stages during the impact of a mast (test 1) are shown in figure 3. The wing impactor penetrated the mast, whereafter the mast failed.

The following failure modes were recognised:
1. Breakage of the front verticals at the impact point.
2. Release of all diagonals, due to bending of the mast.
3. Wrap around of the back verticals.
4. Pull out of the back verticals at the base of the mast.

Damage of the wing impactor is shown in figure 4.

DRI/KRASH

Program DRI/KRASH is referred to as a hybrid modelling technique, which allows a user to provide approximate representations of structural behaviour utilizing existing test data, other analytically developed input properties and/or heuristic reasoning, reference 2. The program is used primarily in the modelling and simulation of aircraft (fixed-wing and rotary-wing) crash impacts and accident investigation. The program has also been used in the simulation of rail-train and automotive crash scenarios. The DRI/KRASH code and derivatives have been used by numerous aircraft manufacturers and agencies including, but not limited to Airbus, Agusta, Bell-Helicopter, CIC, CIRA, DLR, Eurocopter, Fokker, Kawasaki, MDHC, NASA-LANGLEY, NLR, Westland Helicopters and Simula Technologies.

DRI/KRASH MODEL AND ANALYSIS

A DRI/KRASH two-dimensional model was made of the 6 meter high EXEL mast, see figure 5. The model utilizes several DRI/KRASH features, including:
- A moving mass (vehicle/aircraft section structure) impacting a stationary mass (frangible approach light structure).
- Beam property cards to allow quick parametric changes to the mast structure which is of 2 sets of defined beam properties; one for the vertical tubes which have 32 mm o.d. and 28 mm i.d. and diagonal tubes with a 22 mm o.d. and 18 mm i.d.
- Material property cards representing 2 sets of properties associated with glass/fibre/polyester composite lattice structure.
- A standard nonlinear beam representing the wing leading edge in contact with the light stanchion mast contact point for assessing potentially different crush characteristics.

The model size is 28 masses and 47 beams, including 1 nonlinear beam. The simulation duration is .120 seconds at an integration interval of 5E-6 seconds. The purpose of the initial DRI/KRASH runs was to demonstrate feasibility with regard to simulating a moving mass (i.e. aircraft wing mounted on a moving vehicle) impacting a stationary structure (frangible approach light stanchion). The moving vehicle and structure were represented by three masses; truck, impactor steel beam and wing box section, masses 101, 102, 103, respectively. These masses have a prescribed 140 km/h forward velocity. The frangible approach light structure is represented by the other 25 masses, all of which have a prescribed zero velocity. The base of the stationary structure (masses 1 and 13) is anchored to the ground by prescribing large masses (30 kg each) and zero acceleration time histories at the 2 respective masses. The top crossbar with three lights is represented by two 7.5 kg masses (12 and 25). The light stanchion is approximately 6 meters high. The impact point is 3.885 m above the ground at mass 9 of the light stanchion structure. The actual impact point may have been slightly higher (4.1 m). If so that difference will be accounted for in refined future modelling. The DRI/KRASH program allows for user input failure or rupture loads. However, for the initial case presented this option was not activated in order to allow for an observation of the behaviour of the overall behaviour of the structure.

The results without allowable rupture invoked provide movement of the mast, which is more consistent with the energy levels noted in the test report. For example, this latter case shows overall train energy of 39 kNM versus between 33 kNM and 41 kNM in tests 1 & 3, respectively. This represents a difference of about 5 to 15 % between analysis and test.

The overall force as measured on beam 101-102 is around 39 kN versus test between 22kN and 26.4 kN. This is a higher difference between test and analysis (32 to 43 %) than the energy comparison. The wing leading edge as represented by beam 9-103 in the model crushes 0.33 meters versus approximately 0.34 meters, as observed in the post test photographs, or about a 3 % difference.

The overall behaviour of the system is shown in MLS simulation plots (Ref. 3) presented in figure 6.

DISCUSSION

It is shown that the wing impact of a frangible approach light structure can be simulated with the DRI/KRASH code by using a relative simple model. The analysis model behaviour shows both some similarities and differences between that observed during the tests. The excessive rotation of the impactor probably is a result of a lower mass moment of inertia in the model representation than physically exists in the test. This is a parameter than can easily be investigated during the next phase of the study. The choice to not include the effects of vertical and diagonal tube failure or rupture loads prevents a full evaluation of the local behaviour of the structure failure modes. For example, the base of the light stanchion bends and then pulls out during the test. The analysis shows the bending motion, but because no failure loads are included in the model, it falls short of reproducing the latter failure mode. However, again this is additional analysis that will be investigated in the next phase of the study.

The next planned development stage of the research programme is to refine the analytical model and validate the model via correlation with test data. During these ensuing phases of the study it is intended to carry out the following activities:

- Create a 3 dimensional representation of the impactor-mast system.
- Incorporate failure criteria obtained with detail tests on mast components.
- Refine the crushing behaviour of the wing leading edge. A DRI/KRASH type 9 element was used, see figure 7. Updated data will be incorporated into the model and possibly a different type of nonlinear behaviour will be used.
- Adjust the model wing-mast contact point, if necessary.
- Update system mass and stiffness properties.
- Incorporate failure/rupture loads for both vertical and diagonal tubes, and include diagonal beams perpendicular to the impact direction, if appropriate.
- Utilize up to date test time-history data.
- Compare force and energy levels, and deformation and failure modes.
- Develop a design approach, design tools and criteria.
- Evaluate other types of designs and impact conditions, for which test data will be available for comparison purposes.

The initial study, while not detailed with regard to all aspects of the test results, none-the less shows as was intended, that modelling of the interaction between a moving impact mass and a stationary frangible light stanchion is feasible with program DRI/KRASH. Modelling improvements and added test data, as noted in the effort required to complete the study, will further enhance the methodology.

CONCLUSIONS

From the simulations of the impact of the frangible approach light structure and comparison with the experimental results the following conclusions can be drawn:

1) Simulation of a wing impact on a approach light mast structure was possible with DRI/KRASH and proved the suitability of this code for the problem at hand.
2) Simulation of the impact provided meaningful results.
3) The mast model has to be refined and local failure modes must be incorporated.
4) Currently, the next development phase of the research programme is being carried out.

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2 *DRI\KRASH theory reference manual KRASH version 9601*, Dynamic Response Inc., Januari 1996.

3 M Luetzenburger, *MLS KRASH pre-/postprocessing software user' guide*, MLS, 1998.


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Figure 1. General view of the EXEL mast and the test set up


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Figure 2. Impacted EXEL mast

Figure 3. Nine stages of the full scale test on a EXEL mast, test 1 [Ref. 1]

Figure 4. Damaged wing impactor

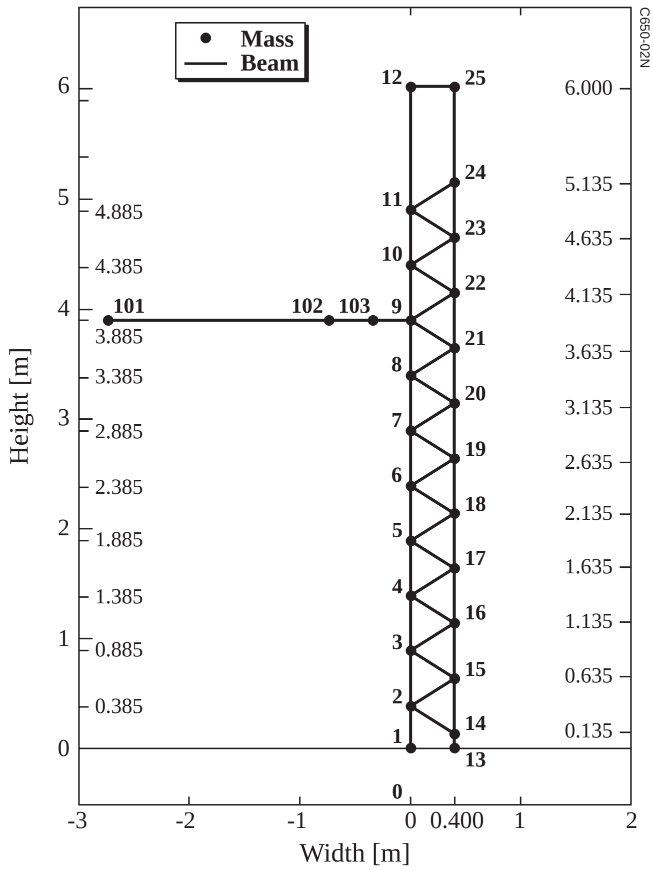

Figure 5. Two dimensional DRI/KRASH model

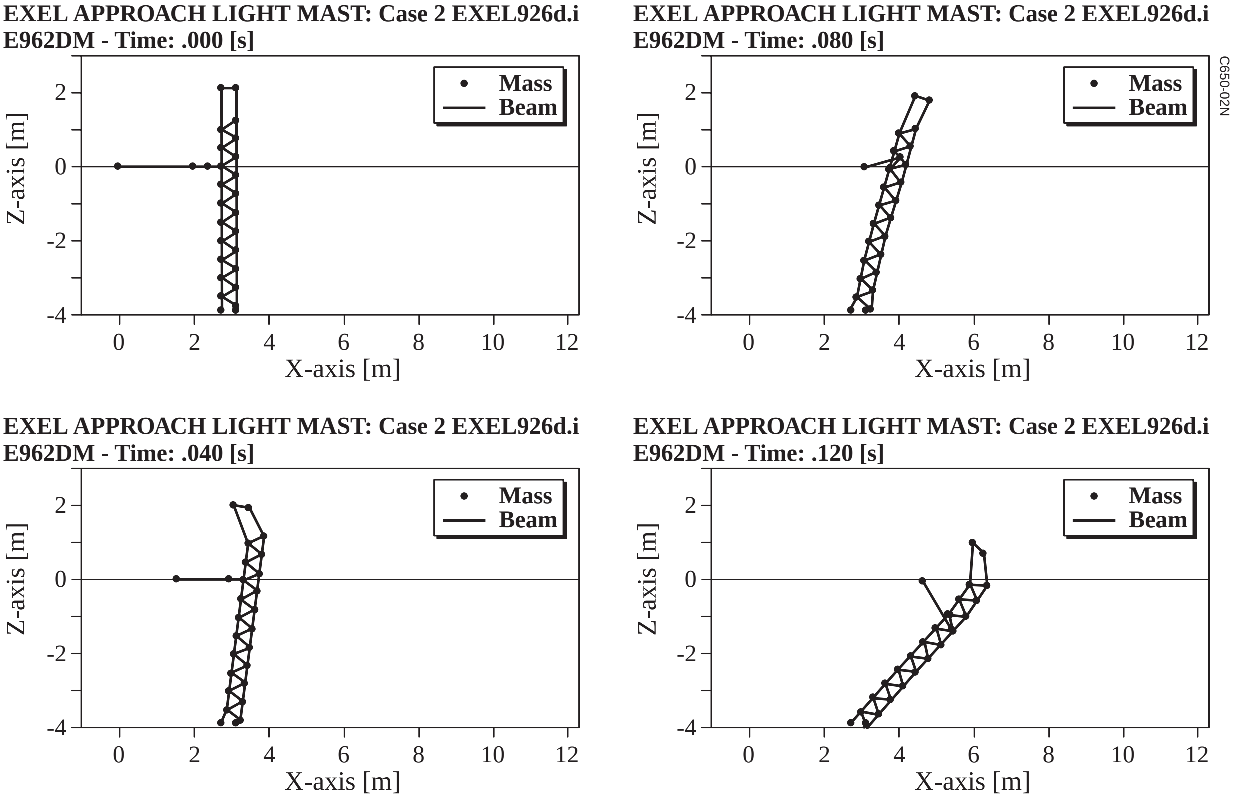

Figure 6. DRI/KRASH simulations of mast impact

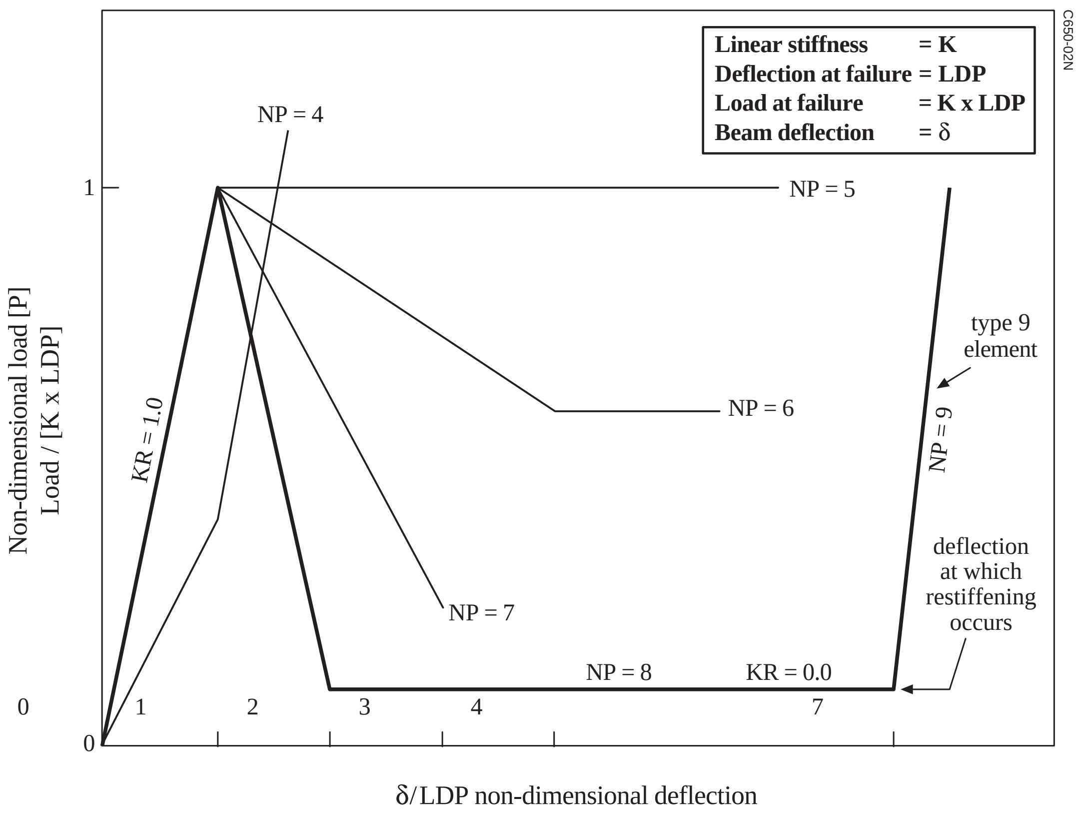

Figure 7. Relationship between KR-deflection and load-deflection data for DRI/KRASH standard tables