

Hail Impact Simulation on CFC Covers of a Transport Aircraft

P. Starke*, F. Mayer
EADS Deutschland GmbH
81663 Munich
Germany

Abstract

Due to increasing weight saving requirements in new aircraft, structures traditionally built from aluminium alloys are increasingly replaced by carbon fibre reinforced Composites (CFC).

For the preliminary flight clearance hail impact simulations were performed on CFC covers. For the composite material the authors applied a user-defined material. Behaviour of ice / hail stone was modeled through fitting of parameters for the Johnson–Cook material model to appropriate test data.

While the precision of simulations was sufficient for a preliminary assessment, further tests will be necessary for permanent approval as well as for refinement of numerical models.

Key words Hail, High-velocity Impact, Johnson–Cook, user-defined material model

1 Introduction

In large transport aircraft, the air conditioning system usually comprises an Emergency Ram Air Intake (ERAI). In case of malfunction in the Air Generating Unit (AGU), the aircraft cabin is pressurised by ram air. Figure 1 shows a typical location of an Emergency Ram Air Intake (ERAI) Scoop in Transport Aircraft.

Due to its position, the ERAI is susceptible to Foreign Object Damage, e. g. through hail impact. In weight-saving efforts as well as due to advantages in manufacturing of double-curved sheeting, in an on-going project Carbon Fibre Composite was chosen as material for ERAI covers.

In the context of a tight schedule in a ongoing project, the application of a rather complex material — which CFC indeed is compared to conventional lightweight alloys — exposed to transient impact loads poses quite a challenge to stress office staff. It turned out that with given restrictions with respect

to schedule, budget and available test specimen during pre-production phase, the problem could be only solved by non-linear structural analysis.

2 Numerical Modeling

The main issues are — besides the definition of representative impact load cases — an appropriate choice of discretisation methods and material models, including the necessary input parameters.

2.1 Impact Load Cases

With respect to distribution of size and probability of impact, there's a noticeable scatter. Thus, several load cases were defined in order to cover such a variety. Figure 2 shows impactor size and impact location for single hail stone impact load case. The hail has the highest mass of all cases investigated here, yet rather an intermediate velocity. Figure 3 shows impactor size and impact location for two hail stones consecutive impact load case. The ice spheres have an intermediate mass and rather high impact velocities. They hit the same site as well. Finally, Figure 4 shows impactor size and impact location for a ten hail stones simultaneous impact load case. Of all cases investigated here, the hail stones have the



Figure 1: Typical location of an Emergency Ram Air Intake (ERAI) Scoop in Transport Aircraft.

*peter.starke@eads.com

lowest mass, yet the highest velocity.

2.2 Hail Stone

Thanks to very satisfactory results achieved in simulation of bird impact [1, 2], SPH method was chosen for modelling of hail stones.

For verification, results from impact simulations of a 42 mm ice sphere on a rigid surface [3] were compared to test results by Kim [4]. Figure 5 and Figure 6 show a comparison of impact force versus time from simulation and test for hail impact at $v_{imp}=73 \frac{m}{s}$ and $v_{imp}=126 \frac{m}{s}$, respectively.

The results from simulation and test differ rather strongly. For assessment of reliability, plausibility of the respective data was checked through comparison with expected maximum forces from momentum transfer. Under the assumption that the process can be idealised rather as inelastic than as elastic, good correlation was achieved for an impact velocity of $73 \frac{m}{s}$ and still a reasonable one for an impact velocity of $126 \frac{m}{s}$. Possibly, the results by Kim were influenced by some oscillatory problems in the data acquisition equipment. Should this presumption turn out to be true, it would indicate high potential for replacing testing of components by numerical simulations. While the results presented here as a first attempt look quite promising, further testing throughout the entire range of temperature and strain rate is necessary in order to improve reliability.

2.3 ERAI Cover

Previous bird impact simulations [1, 2] had shown the necessity of taking into account effects of dynamic loading on composite materials. A material model having some capabilities was developed [5], implemented [6] and verified [7].

As an illustrative example for the effects of dynamic loading of CFC, Figure 7 and Figure 8 show the deformation and damage pattern from small bird impact simulation using *MAT.54 and the authors' extended composite model in comparison to the damage pattern from small bird impact test in Figure 9.

An appropriate representation of failure in the laminate is essential for obtaining realistic behaviour of the ERAI cover. In user-defined material models definition of erosion criteria is somewhat cumbersome — at least at the authors' level of experience. Given the choice of element erosion after failure in one integration point or no element deletion at all, the authors picked the second option. In consequence, the laminate had to be modeled in a so-called stacked-shell approach, i. e. every unidirectional (UD) layer of the laminate had to be discretised by a layer of shell elements. The respective layers

were connected by beam elements. Figure 10 shows a unit cell of the Finite Element (FE) mesh for the ERAI cover.

3 Simulation Results

Figure 11 shows the deformation sequence a consecutive impact of two hail stones. A delamination pattern resulting from this impact loadcase is shown in Figure 12.

As the extent of delamination was rather minor and no fibre failure occurred in the simulation, the results were deemed good enough to grant an initial flight clearance. For a final certification, hail impact tests are still necessary. Especially, further testing of composites under high strain-rate loading at low temperatures is necessary for improvement of material models as well as for enhanced reliability of the respective input parameters.

4 Summary and Outlook

Hail impact simulations have been performed for initial flight clearance of a CFC cover. Compared to a conventional testing approach, a remarkable reduction in cost and duration has been achieved. For composite parts, the authors took benefit from the opportunities of implementing user-defined material models in LS-DYNA. For modeling of hail stones, *MAT_JOHNSON-COOK was chosen. Considering the similarity of recrystallisation near melting temperature with respect to its effects on strength both for sweet water ice as well as for some metals, an extension of the material model could be beneficiary.

For improvement of both a better understanding of material behaviour as well as for improved reliability of parameters for existing material models, extensive testing of coupon-size specimens in a wide range of strain-rate and temperature is advisable.

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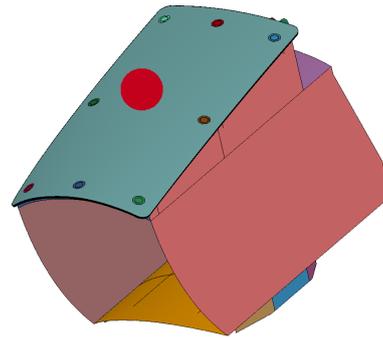


Figure 2: Impactor Size and Impact Location for Single Hail Stone Impact Load Case.

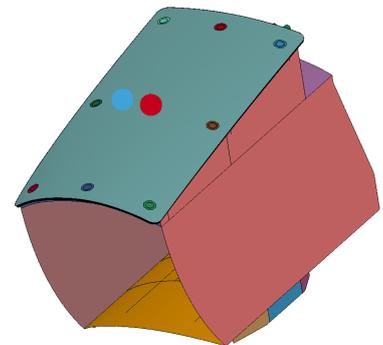


Figure 3: Impactor Size and Impact Location for two Hail Stones consecutive Impact Load Case.

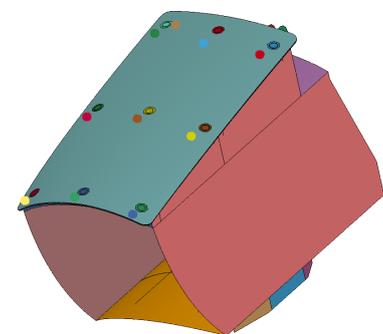


Figure 4: Impactor Size and Impact Location for ten Hail Stones simultaneous Impact Load Case.

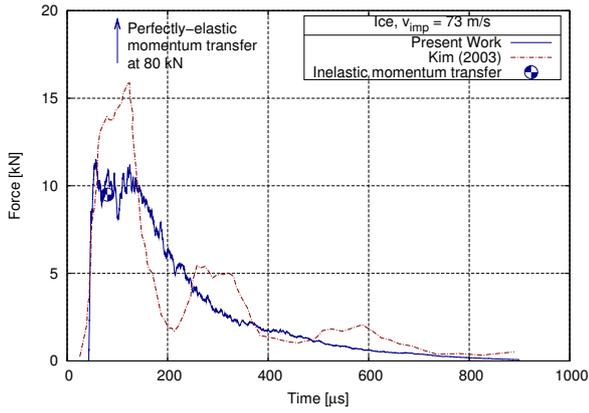


Figure 5: Comparison of Impact Force versus Time from Simulation and Test for Hail impact at $v_{imp}=73 \frac{m}{s}$.

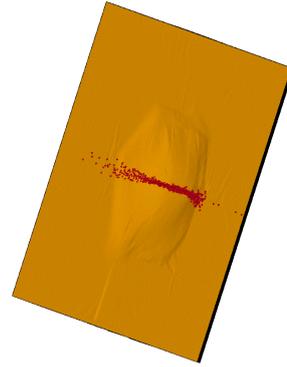


Figure 8: Damage Pattern from Small Bird Impact Simulation using the authors' extended composite model.

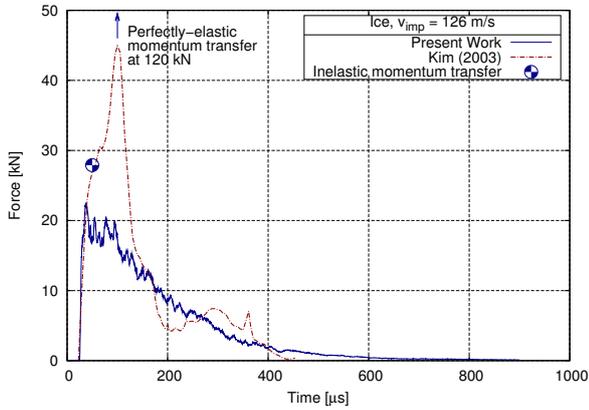


Figure 6: Comparison of Impact Force versus Time from Simulation and Test for Hail impact at $v_{imp}=126 \frac{m}{s}$.

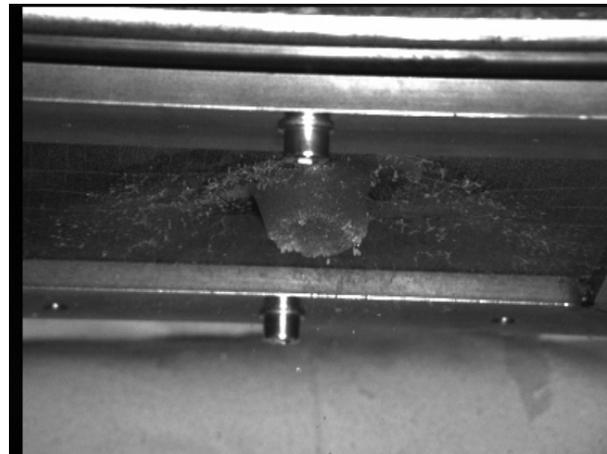


Figure 9: Damage Pattern from Small Bird Impact Test.

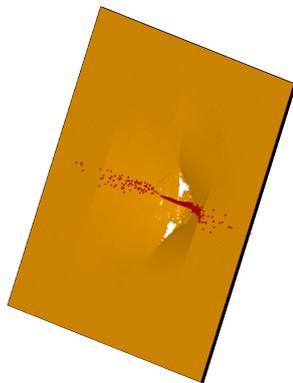


Figure 7: Deformation and Damage Pattern from Small Bird Impact Simulation using *MAT_54.

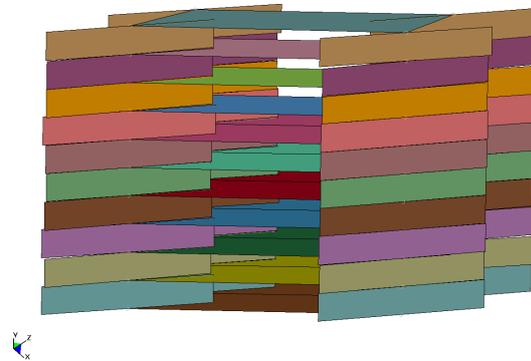


Figure 10: Stacked-shell approach for discretisation of the ERAI cover laminate

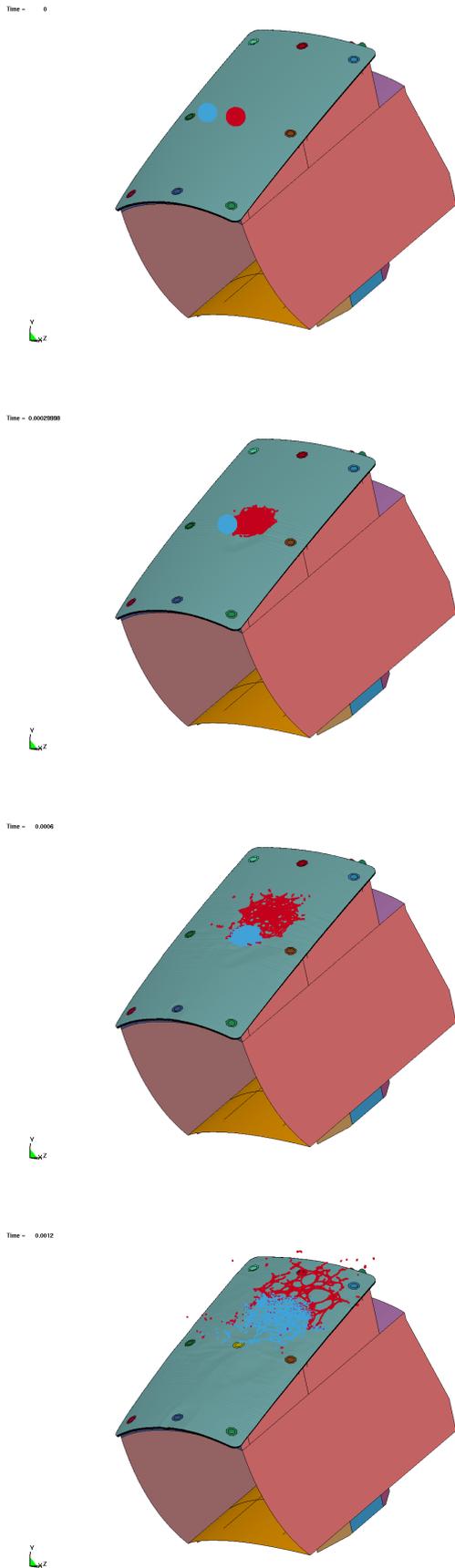


Figure 11: Deformation sequence for the two hail stone consecutive impact

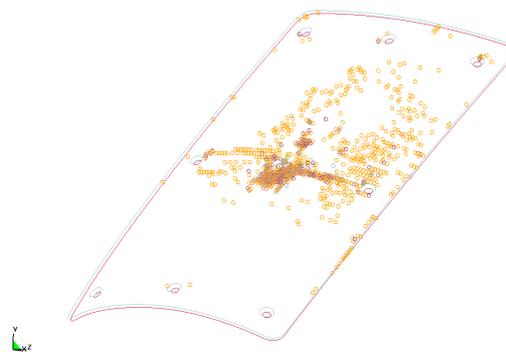


Figure 12: Delamination pattern for the two hail stone consecutive impact