BirdStrike

Investigation of Bird Strike criteria for Natural Laminar Flow wings

State of the art – Background

Amongst the important events during the aircraft service life, for which the structural safety of a wing structure must be certified, is the impact of a bird (bird strike). High velocity impact by birds during flight is a particular concern and may have catastrophic consequences. Especially for the cases of Natural Laminar Flow (NFL) wings, which might have lower airfoil thickness, discontinuous ribs, flexible Leading Edge (LE) skins, monolithic construction and other unconventional characteristics, the LE structural concepts are particularly vulnerable to bird strike, resulting to a very sensitive design issue, which requires special care to be taken during the design and certification process.

In both CS (from EASA) and FAR (from FAA) safety requirements, it is stated that analytical methods, such as numerical analyses, can be an acceptable mean of certification, provided that they are validated by tests carried out on sufficiently representative structures of similar design. However, the numerical simulation, mainly by means of Finite Element (FE) analysis, of high speed bird impact involving composite materials and complex structures is not an easy task. Except from the explicit Lagrangian approaches, bird-strike impact has been simulated using Eulerian, and ALE approaches, which are available in some commercial explicit FE codes. More recently, the Smoothed Particle Hydrodynamic (SPH) approach has been proposed amongst others, as an attempt to model continuum physics avoiding the limitation of grid based finite difference methods.

In the last fifteen years there have been a series of EU research projects concerned with the crash and impact response of aircraft structures, with efforts towards the reliable modelling of the behaviour of advanced materials (metals and composites) under crash and impact loads, as well as with code developments to establish valid FE simulation tools for aircraft structures under dynamic loads. However, the bird strike impact behaviour of a complex monolithic CFRP leading edge section, designed such that it flies in NLF conditions has not been studied in any of the above mentioned projects.

Objectives

The BirdStrike project aimed to establish a validated bird strike analysis capability, which enables the Smart Fixed Wing Aircraft (SFWA) partners to simulate bird impact on a Carbon Fibre Reinforced Polymer (CFRP) Leading Edge (LE) of a Natural Laminar Flow (NLF) wing. This has been achieved by setting up a combined program of testing and analysis / simulation to determine the extent of damage and validate the composite material failure criteria applicable for the simulation of bird-strike on leading edge panels of NLF wings.

Description of work

In the frame of BirdStrike project the following main activities have been performed:

1. Development of a FE numerical methodology based on the stacked-shell approach for the efficient simulation of bird-strike incidents on composite panels.
2. Manufacturing of flat un-stiffened and stiffened composite panels that include supporting stringers, sparcaps and other structural features.
3. Design and analysis of a supporting frame for bird-strike impact tests on composite panels.
4. Bird-strike tests and NDI analysis on composite panels.
5. Development of FE models of the un-stiffened and stiffened panels bird-strike tests.
6. Validation of analyses and numerical models based on experimental results and measurements.
7. Development of a numerical model to predict the extent of damage in a representative composite LE geometry.

Results

Three different types of structural components have been planned to be manufactured, tested and simulated in the frame of BirdStrike project:

- flat un-stiffened panels
- flat stiffened panels
- full scale LE structure (this specific test item has not been manufactured and tested in the frame of BirdStrike project)

Test specimens have been made of M21E/IMA UD composite material. In the case of stiffened panels, due to the existence of multiple stiffening elements a complex mould has been required for the manufacturing of the stiffened panels. The mould consists of CNC-milled aluminium parts designed to take into account the individual process parameters e.g. thermal expansion during the curing process. Using the chosen mould concept for manufacturing the entire specimen could be manufactured in one curing step. A stiffened panel manufactured by CI is presented in Figure 1.

Figure 1: Finished stiffened panel

Bird-strike experimental tests have been performed on both stiffened and un-stiffened flat CFRP panels, after designing and manufacturing of a proper supporting frame. Moreover, NDT inspections have been performed on the panels before and after the impact tests. Three impact tests have been performed on flat un-stiffened panels and two tests have been performed on flat stiffened panels. Bird-strike tests have been performed in the POLIMI bird testing facility, shown in Figure 2.

A Digital Image Correlation system and a shearography system (Q-800) has been used by DANTEC at the panels before and after the impacts. Analyses of the measurements before the impacts verified that no initial damages exist in the panels. Analyses after the tests have been perform to assess the damages developed in the panels due to the bird-strike events. A typical image from laser shearography applied at one of the impacted stiffened panels is presented in Figure 3.

For the numerical simulation of bird-strike incidents on composite structures, the stacked-

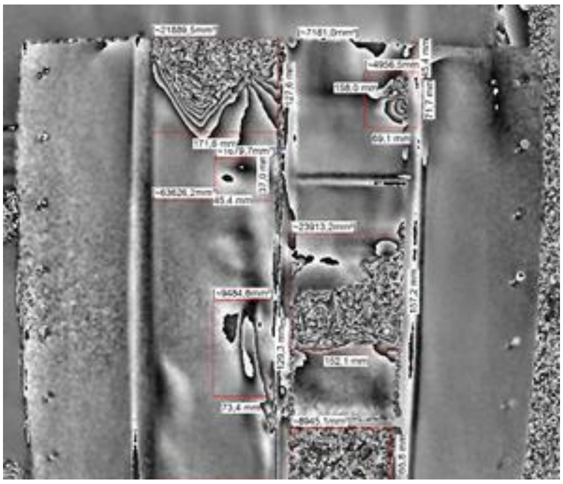

Figure 3: Delamination damage detected at stiffened panel due to bird-strike impact

shell approach has been developed and applied, as a promising alternative to the classical solid and shell elements approach. In the stacked shell approach (described as 2.5D approach) the behaviour of a laminated composite structure is expressed by the behaviour of an interactive set of sub-laminates, each of which exhibits constant through-thickness transverse displacement and shear strains. In this sense, the stacked shell method verges on the behaviour of laminates in a layer-wise manner, enabling a much more accurate determination of interlaminar stresses, compared to FSDT and CLT single-sub-laminate solutions. The FE modelling procedure when the stacked-shell approach is followed involves two basic steps: initially sub-laminates are generated using shell elements, which constitute a fraction or a number of the layers of the composite structure; consequently, contact interfaces representing the matrix inter-layers are generated. The stacked-shell approach and all numerical simulation of bird-strike incidents have been implemented using LS-DYNA commercial explicit FE code.

FE models for the simulation of flat un-stiffened and stiffened panels bird-strike tests have been developed. Results of numerical simulations of bird-strike on these panels are compared to respective experimental measurements and findings.

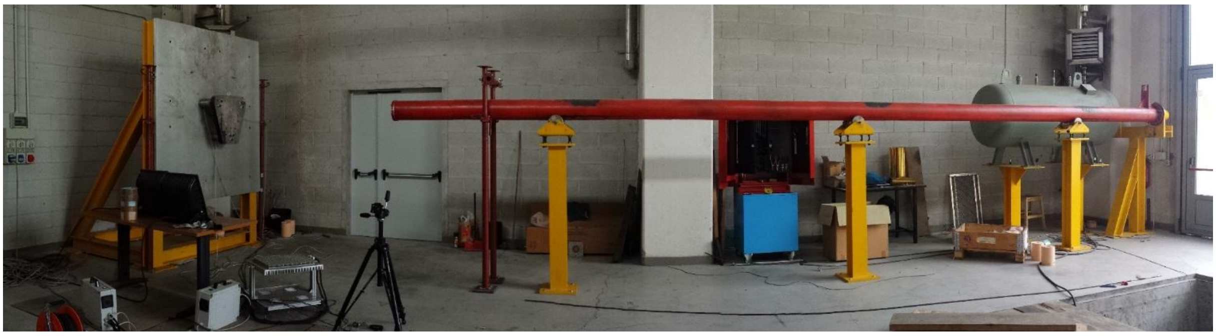

Figure 2: POLIMI bird testing facility

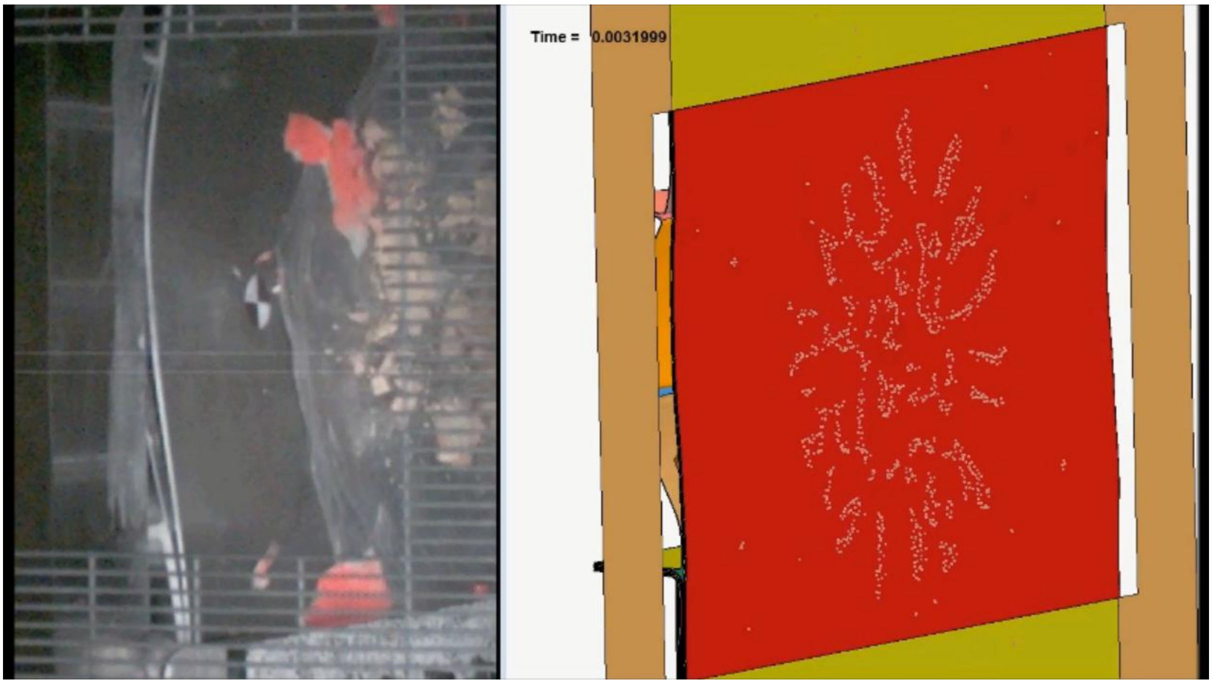

Figure 4: *High speed camera frame (left) and numerical simulation calculated deformed shape (right) for the stiffened panel impacted by a bird with 175m/s speed 3.2 ms after impact initiation*

In order to validate numerical simulation models, extensive comparison of panels calculated global behaviour and respective high speed camera images, have been performed for all simulated tests. In Figure 4 an indicative comparison of a stiffened panel deformed shape obtained by the high speed camera and the numerical simulation are presented. It has been generally observed that the deformed shapes obtained by the FE analyses are in very good agreement to the respective high speed camera images.

It has been, thus, concluded that the numerical models developed based on the stacked-shell approach are efficiently simulating the composite structures behaviour. Some overestimation of the delamination is observed, that might be due to the static interlaminar material strengths used.

The full Leading Edge FE model using the stacked-shell approach has been developed and solved for characteristic bird-strike cases. In Figure 5 calculated displacements of the full Leading Edge structure due bird-impact are presented.

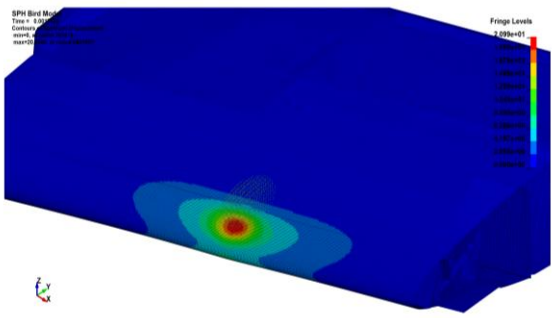

Figure 5: Full LE structure calculated displacements due to bird-strike (1.8 ms after impact)

Timeline & main milestones

The initially planned project duration has been 18 months. However, due to significant delays related to material availability, the project duration was finally extended to 42 months. The main project milestones were:

- Manufacturing and bird-strike testing of flat un-stiffened and stiffened prototype panels
- Development of numerical simulation approach based on the stacked-shell approach
- Application to the simulation of bird-strike tests on flat panels and full LE structure.

Environmental benefits

The introduction of a laminar wing section on the aircraft and the absence of leading edge slats results in a geometry that is outside of the range of validation for existing numerical models and bird strike simulation. Research performed and numerical simulation tools developed in the frame of BirdStrike project have closed the gaps in knowledge that relates to this scenario. Thus, project results will contribute to the objectives of reduced fuel burn and emissions reduction, by the application of Natural Laminar Flow applied to a Short Range Aircraft (SRA) concept.

Dissemination / exploitation of results

Project results have been primarily disseminated by scientific publications. Projects results are mainly exploited by the Topic Manager, while project participants are mainly benefited by the evolution of capabilities related to numerical simulation and complex composite structures manufacturing.

Project Summary

Acronym:	BirdStrike
Name of proposal:	Investigation of Bird Strike criteria for Natural Laminar Flow wings
Involved ITD	Smart Fixed Wing Aircraft ITD
Grant Agreement:	CS-GA-2013-307612
Instrument:	Clean Sky
Total Cost:	797,480€
Clean Sky contribution:	599,360€
Call:	SP1-JTI-CS-2011-03
Starting date:	January 2013
Ending date:	June 2016
Duration:	42 months
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