COMPOSITE SANDWICH PANEL BIRDSTRIKE TESTING AND ANALYSIS

R Gibbon*, L Vaughn*, D Coldbeck**
***Frazer-Nash Consultancy, **Spirit AeroSystems Ltd**
r.gibbon@fnc.co.uk; l.vaughn@fnc.co.uk; david.coldbeck@spiritaero.com

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Abstract

A bird strike test campaign has been performed on a number of composite honeycomb panels, representative of a typical composite Fixed Leading Edge (FLE) structure. The primary purpose of the test campaign was not to test in-flight vulnerability, but to provide correlation with analytical predictions. Impact scenarios were devised to aid the development of the novel analytical tools rather than be realistic impacts.

A detailed finite element model of the test specimen was developed and pre-test predictions of damage were provided from Non-Linear Finite Element Analysis (NLFEA) using Abaqus Explicit. The analyses were repeated post-test and methods reviewed and developed to improve correlation of predictions with test observations.

NLFEA methods for composite materials were developed during this study, and ultimately the correlation of prediction with test was significantly improved across a wide variety of impact scenarios. In particular, there is generally very good correlation between test and analysis for impacts onto the honeycomb region of the composite panel where large-scale bending and in-plane failure dominate. However there is still room for improvement in the analytical methods; for impacts adjacent to ribs, where through-thickness shear failure dominates the panel behaviour, the analyses are overly conservative.

1 Introduction

Understanding and being able to predict the behaviour of composite materials when subjected to impact damage is critical to their widespread use on aircraft. Without reliable predictive tools, such as Non-Linear Finite Element Analysis (NLFEA), the cost of physical testing to ensure that composite components are suitable would be prohibitive.

To this aim a programme of work was devised to develop a numerical method for modelling and predicting the results of bird strike onto composite honeycomb panels, and determine the confidence in, and limitations of, the resulting method.

2 Modelling Approach

A simplified, but realistic, test-rig was designed for the programme which represented a typical composite FLE (Fig. 1). The top and bottom wing covers were monolithic carbon fibre composite. The J-Nose and lower cover panels were of a sandwich construction with carbon fibre over a honeycomb core. The riblets and spar were made from aluminium alloys.

The majority of the modelled structures were meshed using conventional shell elements, but continuum shell elements and solid elements were also used where appropriate, with a resultant mesh size of between 6-10mm.

The composite materials were modelled using a Hashin failure criterion and the metallic materials using a typical elastic-plastic definition.

The model was fully built-in at the points where it connected to the test rig. General contact was defined for the whole structure so that all components could interact with each other and transfer load through the structure.

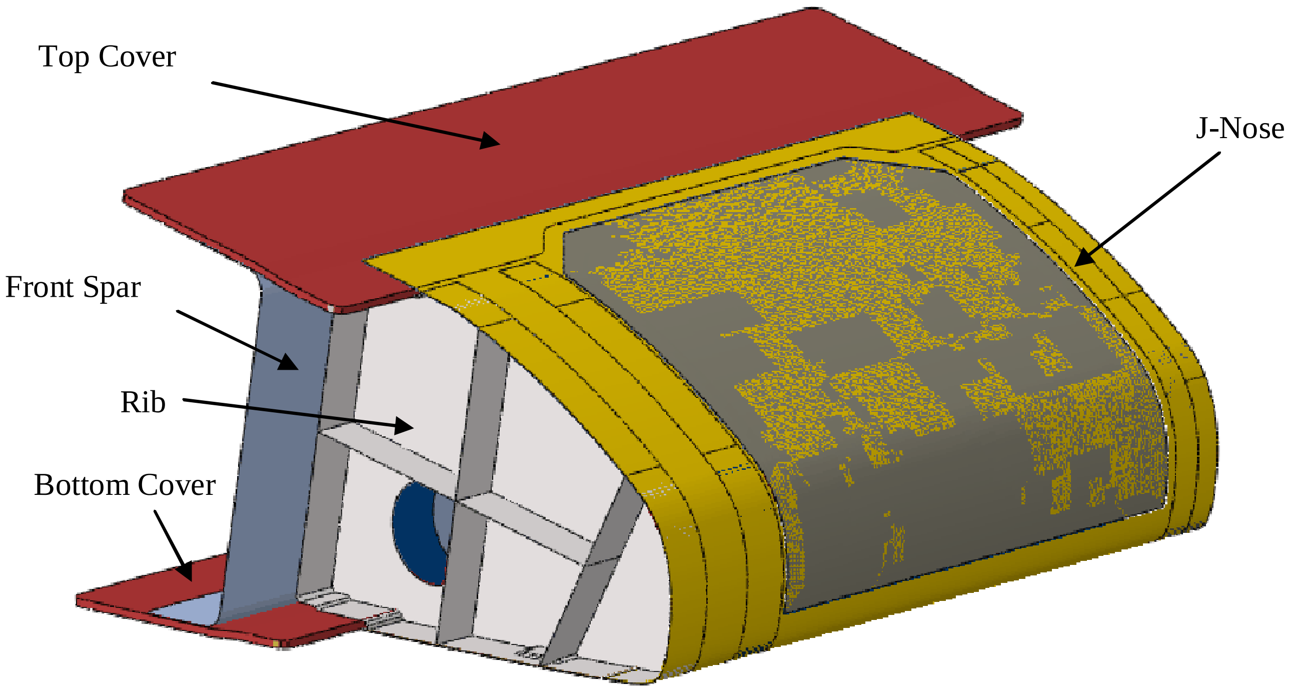

Fig. 1. Geometry Included In Test Specimen NLFEA Model

The bird was represented as a cylindrical entity with domed ends, with a mass of 4lb (1.81kg).

3 Test Methodology

Due to their complex construction, composite honeycomb structures can exhibit a large number of failure mechanisms. These include dis-bond, delamination, in-plane and through-thickness shear fibre failure, core crushing, fastener failure and fastener pull-through. An analytical method to model these materials would, ideally, be able to capture all of these mechanisms. It is often difficult to distinguish between the importance of each of these failure mechanisms, since in typical bird strike impacts a number of them will be evident and contribute to the overall damage caused.

Therefore the testing had two objectives: 1) impacts that as far as possible isolate individual material failure mechanisms; 2) impacts that are representative of normal flight conditions. This dual approach would therefore allow the analytical methods to be investigated and determine which failure mechanisms could be represented most accurately, and also provide valuable test-cases to investigate the severity of damage created by typical in-flight impact scenarios.

The test programme was therefore divided into two tranches, reflecting these two objectives. Pre-test analyses were carried out to define each tranche, specifying the impact locations, angles and velocities. Post-test analyses were then used to address any differences between the specified and actual impact conditions or changes to the modelling to better correlate with the results.

4 Tranche 1

Five tests were completed in this tranche. A range of velocities were used with impacts on both the monolithic and honeycomb regions of the J-Nose, either normal to the panel (90°) or at 70° (Fig. 2). Through-thickness shear was the dominant failure mode where the impact was adjacent to a riblet. Fibre failure, delamination and disbond were prevalent otherwise.

All the test results were more severe than the pre-test predictions. The energy required to fail the J-Nose panel was over-estimated, particularly with regard to through-thickness shear.

The analytical methods were reviewed and a number of changes to the modelling of the panels were made. These included tied interfaces within the model and material definitions to better reflect the as manufactured

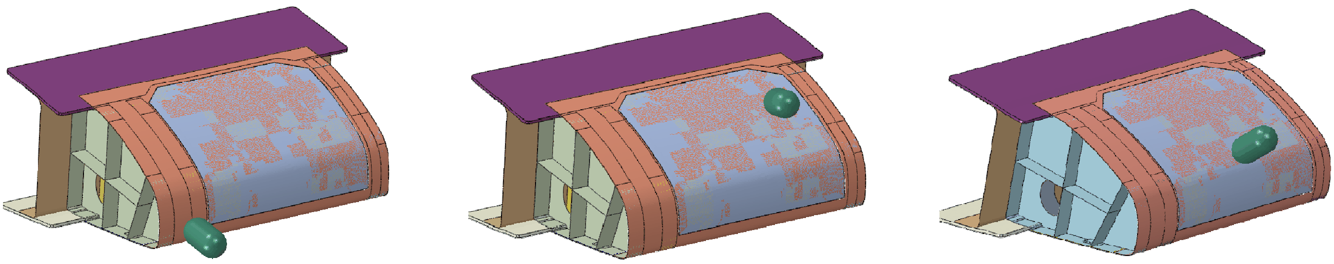

Fig. 2. Example Impact Scenarios Used During Tranche 1

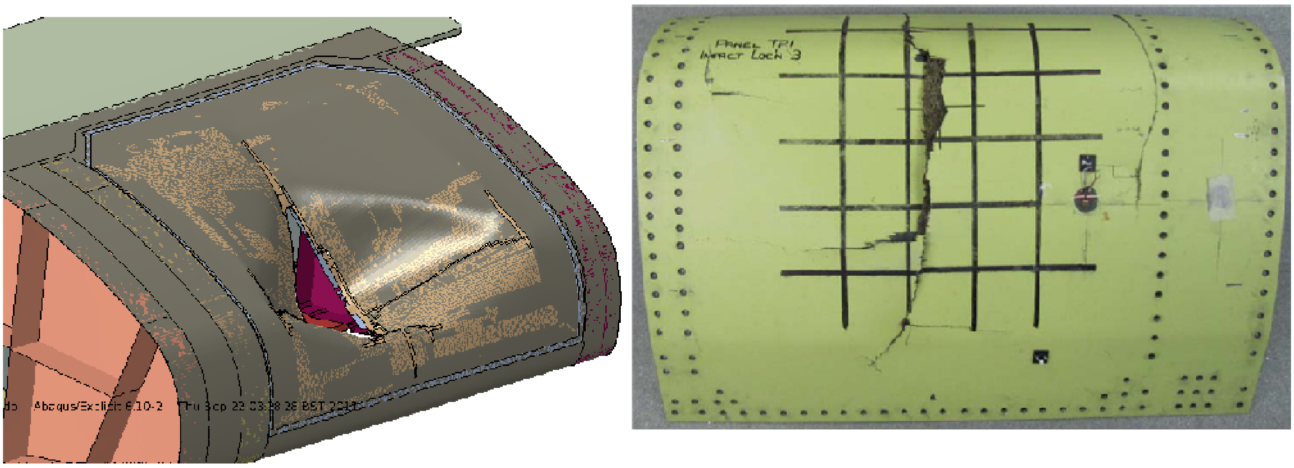

Fig. 3. Illustrative Post-test Correlation Achieved For Tranche 1

properties of the panels when subjected to high speed impacts.

The correlation of the analytical predictions was significantly improved by using the updated methods. The threshold of failure appeared to be captured with reasonable accuracy, given the limited number of tests against which correlations can be made. Impacts onto the monolithic region predicted failure and penetration, as was observed in test. The impacts onto the honeycomb region showed good correlation with test, both in the severity and location of damage, as illustrated in Fig. 3.

5 Tranche 2

Six tests were completed in this tranche. Three different impact locations were tested at two different velocities so that the threshold for penetration could be determined. Again a range of velocities were used, with impacts on the honeycomb of the J-Nose at an angle of 36° to represent the wing sweep of the FLE.

The analytical predictions of the results correlate with good accuracy the severity and location of damage for impacts onto the honeycomb. Correlation of the onset of penetration, where damage is just severe enough to allow bird debris through the J-Nose panel, is also good, see Fig. 4.

The analyses predicting results for impacts where the bird debris did not strike the central region of the panel, but impacted towards the rib, correlated less well with test (Fig. 5). For these impacts, where the panel was predicted to shear against the hard point of the rib, the predictions were very conservative, with failure predicted in the analysis that was not observed during testing.

6 Conclusions

The structure of the study, splitting testing into more than one distinct tranche, and focussing the first tranche on isolating individual failure modes, is judged to have been successful. The analytical methods have been improved significantly, and it is understood which failure modes, and so impact scenarios, the methods are less reliable for.

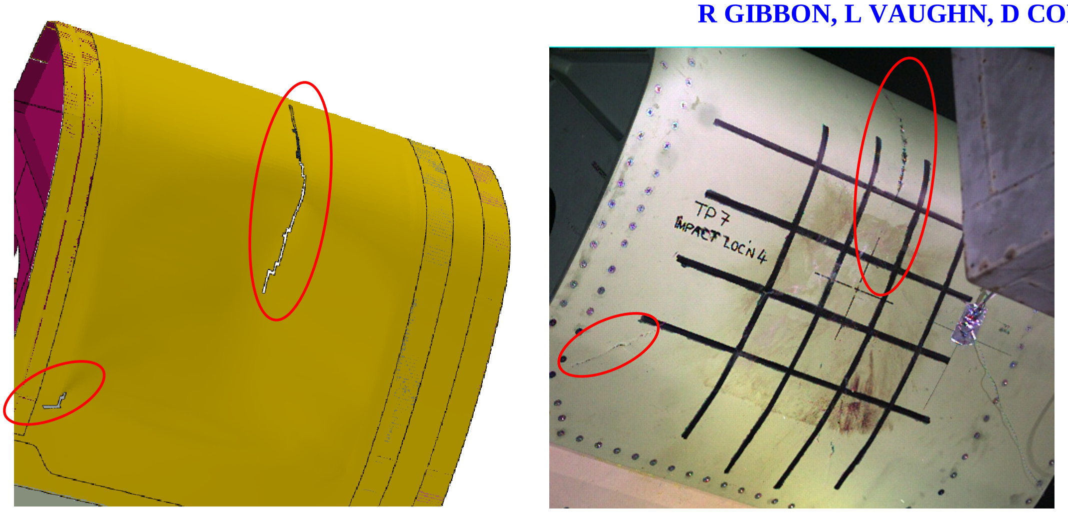

Fig. 4. Illustrative Correlation Achieved For Centre Impacts In Tranche 2

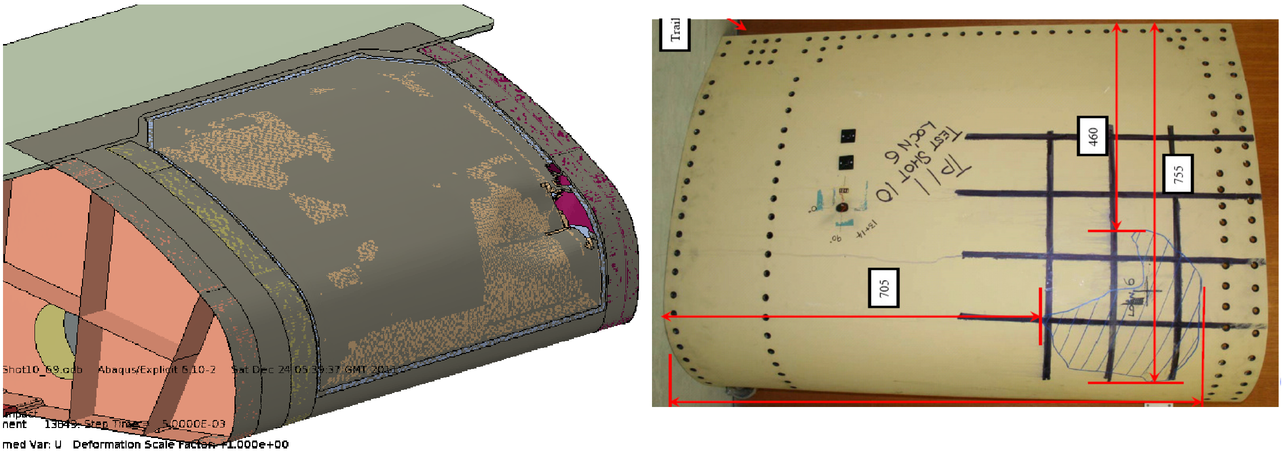

Fig. 5. Illustrative Correlation Achieved For Edge Impacts In Tranche 2

For impacts that are onto the central region of the honeycomb panel the analytical methods are judged to produce predictions to good accuracy and are suitable for initial design assessment. For impacts where through-thickness shear is a significant failure mode the analytical methods are still suitable, but it should be noted that the predictions are likely to be very conservative.

It was found that, given the accuracy of the new methods, it is possible to highly optimise the design of composite panels, partly by ensuring that components are able to meet their requirements but also reducing weight by avoiding over-engineering.

However it is judged that these methods are now approaching the limit of what is achievable using conventional shell elements in the current way. Conventional shell elements, by definition, take no account for through-thickness-shear, so it is not surprising that this is the area where the correlation of predictions to test is weakest. In order to account for through-thickness shear either different element types will have to be used, or a VUMAT developed to work alongside, or instead of, the existing Hashin failure criteria.

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