SOME APPLICATIONS OF LS-OPT TO BIRD IMPACT SIMULATION

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ABSTRACT

This paper describes the application of LS – OPT for assessment of the influence of stochastic effects in bird strike events. To address the problem, a two – step approach has been chosen. In the first step, LS – OPT has been used in order to automatically determine the penetration velocities for different impact sites.

In a second step, LS – OPT was used to create a response surface from the calculated penetration velocities. Subsequently, for a given scatter in the impact site the resultant statistical distribution has been determined by LS – OPT.

KEYWORDS:

Bird impact; Response Surface Method; LS – OPT

INTRODUCTION

Bird Strike incidents are a serious threat to aircraft. Thus, compliance with certification regulations concerning these events has to be substantiated. The traditional ways are tests. Experiments, yet, show limitations in many ways.

In order to validate simulation methods, a research project has been carried out at EADS Military Aircraft [1,2]. Figure 1 shows the geometry of the test specimen. The simulation methods developed there allow to predict damage caused by bird impact with a fairly good precision, as the comparison of predicted (white line) and the failure pattern observed in the test, see Figure 2, shows.

In the tests a deviation in the impact site of real birds of presumably half a bird diameter was observed. This raised the questions whether the impact site – chosen rather by engineering judgement – actually is the most critical one, i.e. it yields the lowest penetration velocity and how large is the influence of variation in the impact site on the change in penetration velocity.

Another question to be raised was the precision of material data for the composite material. Due to the lack of an appropriate material model taking into account strain – rate effects on failure stress, the values had to be "tuned" manually to the highest strain rate observed during the impact simulation.

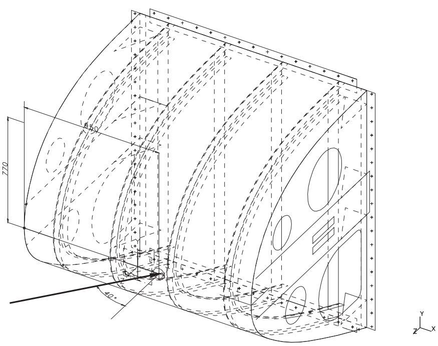

Figure 1: Geometry of test specimen

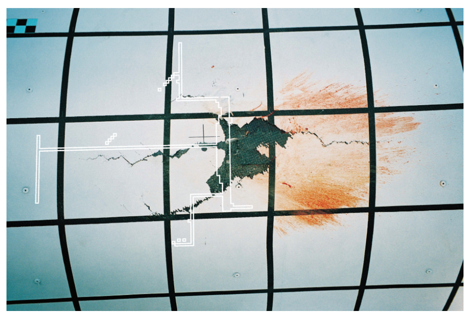

Figure 2: Comparison of test and simulation (white lines) results

In order to answer the questions raised above, a company – funded research project had been started. Its basic idea was to eliminate as many sources of uncertainty as possible and assess the impact of the remaining scatter in results by application of response surface method.

Strain – rate dependent material strength of composites in the range of typical bird impact velocities defined by airworthiness certification regulations was determined by coupon – size tests in conjunction with simulations [2]. Future improvements concerning material modelling are described in the outlook at the end of this paper.

APPLICATION OF LS – OPT

LS – OPT was applied in a two – step process. In the first step, the penetration velocity for various impact sites along the x – axis, see Figure 1, was determined. In the second one, LS – OPT was used to create a response surface from the calculated penetration velocities. Subsequently, for a given scatter in the impact site the resultant statistical distribution has been determined.

DETERMINATION OF PENETRATION VELOCITY

In order to determine the penetration velocity for a distinct impact site, an optimisation problem was formulated. Minimisation of the bird's impact velocity was chosen as objective. As a constraint, the internal energy of eroded elements had to be larger than zero. The number of iterations for each impact site was limited to ten. *Successive Random Search* was selected as optimisation method.

Figure 3 shows the typical evolution of impact velocities for lower and upper limits in the course of optimisation iterations. Both curves show a stable convergence and – after ten iterations – reach a value that is sufficiently precise. Figure 4 shows penetration velocities for various impact points along the x – axis. In Figure 1 and Figure 8 the reader can see that the reference impact point is near a stiffener rib, thus yielding one of the lowest impact velocities. Thus, for small deviations along the x – axis in both directions of the reference impact site, the decrease in stiffness yields higher penetration velocities.

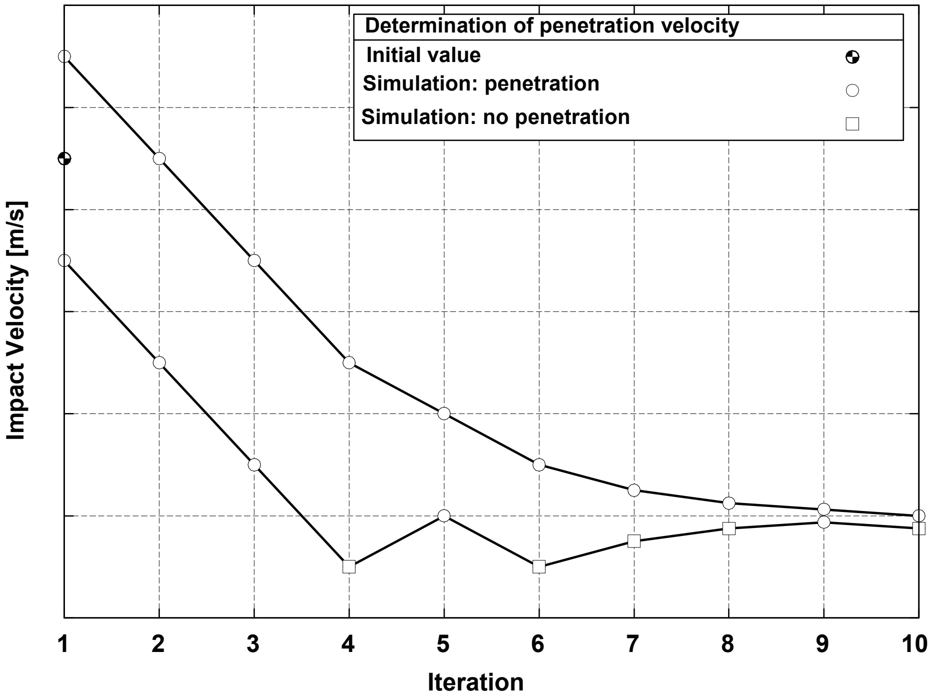

Figure 3: Convergence of impact velocity in the course of optimisation iterations for a distinct point

GENERATION OF RESPONSE SURFACES

With penetration velocities obtained for impact points near the reference impact site, see Figure 4, a 2nd order Response Surface was created by LS – OPT, as shown in Figure 5. In Figure 4 also the 2nd order polynomial equation with coefficients determined by LS – OPT is plotted. The curve fits very well to the data.

As the test specimen had four equidistant stiffener ribs, impact sites located farther from the reference point were expected to have penetration velocities and reaching a maximum value at the most compliant point, located roughly at mid – distance between two ribs. Figure 6 shows these additional data in comparison with the Response Surface from Figure 4 and Figure 5. As it had been expected, the 2nd order polynomial equation could not cover the structural behaviour at this range any more. Due to the periodicity of the stiffening ribs, and thus the periodicity of the specimen's compliance, a Fourier – type approximation was deemed to be more suitable. Since only linear, 2nd order polynomial and Neural Network Response Surface types are available in LS – OPT, the Neural Network approach was chosen to describe the rather global behaviour. Figure 7 shows the Response Surface generated by LS – OPT.

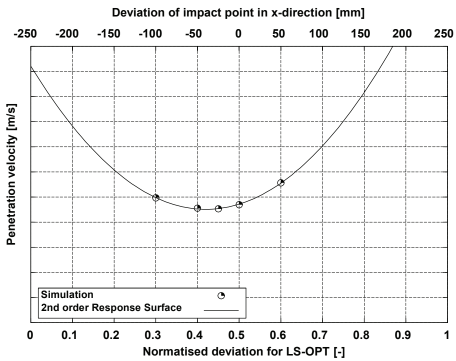

Figure 4: Penetration velocities for various impact points along the x – axis

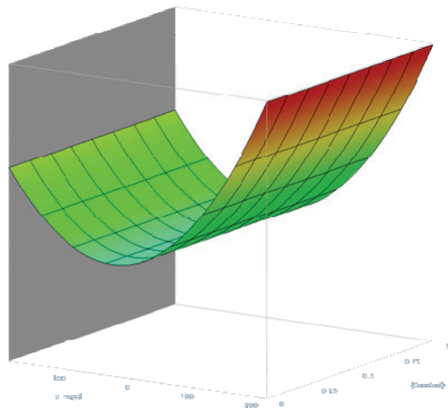

Figure 5: 2nd order Response Surface generated by LS – OPT

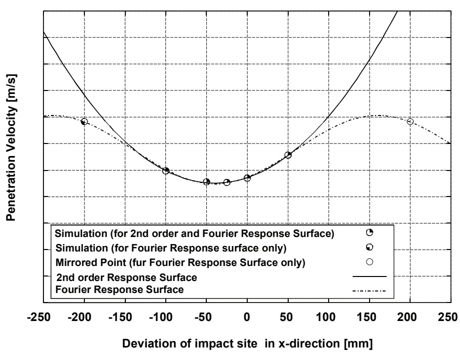

Figure 6: Comparison of 2nd order and Fourier Response Surfaces

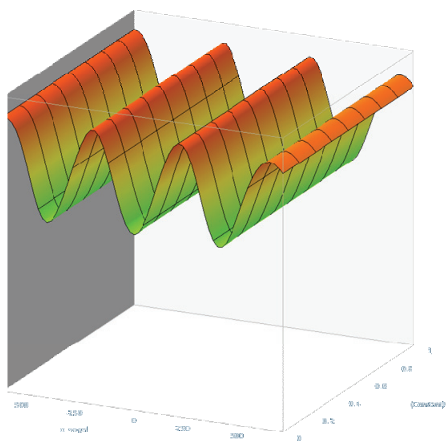

Figure 7: Neural Network Response Surface generated by LS – OPT

INVESTIGATION OF STOCHASTIC EFFECTS

For the investigation of stochastic effects, a Gaussian normal distribution was presumed to be valid in order to describe the scatter of impact sites. With an engineering judgement approach, the authors decided that a standard deviation of 50 mm, i.e. 50 % of a standard bird diameter, would be sufficient to represent scatter of the bird's impact point that could not be detected from high speed imaging or other test data. Figure 8 shows the statistical distribution of impact sites resulting from these assumptions.

Due to its simplicity and sufficient precision in the area of interest (and also due to the authors' lack of experience concerning Neural Networks) 2nd order polynomial Response Surface was chosen.

The scatter of penetration velocities resulting from the scatter in the impact site location is shown in Figure 9. The reader can see that, with a scatter of ±50 mm for the impact site, the penetration velocity can be assumed as almost constant. The investigations also showed that the impact site chosen for the test was most critical and a deviation of the impact site would only cause higher penetration velocities.

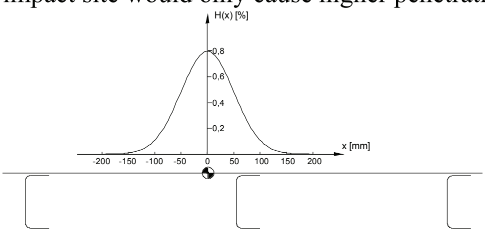

Figure 8: Statistic distribution of impact site

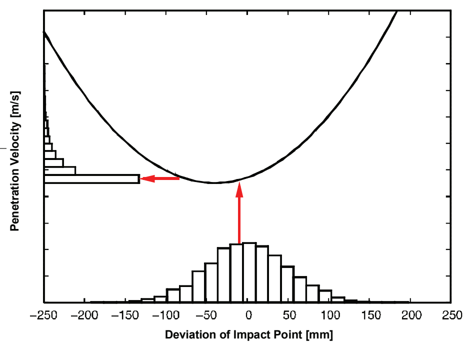

Figure 9: Application of Response Surface for determination of penetration velocity distribution

SUMMARY AND OUTLOOK

The utilisation of LS – OPT confirmed the appropriate choice of the most critical impact site for bird strike tests on a composite leading edge carried out at EADS Military Air Systems. Additionally, the automated calculation of penetration velocities provided an improved understanding of the global bird impact behaviour of the structure.

The available computer power limited the presented investigations to variation of impact site in x–direction. First simulations with deviation of the impact point in both x– and y– direction show very promising results. Figure 10 and Figure 11 show 2^{nd} order polynomial and Neural Network Response Surfaces generated by LS – OPT using these results (together with some assumptions and mirrored data points). Although the Neural Network Response Surface in Figure 11 shows some artificial waviness, the authors see for this type of Response Surface the highest potential for future applications. With some additional data the precision is expected to increase, while the opportunity to find minima or maxima which are less locally restricted than using the 2^{nd} order polynomial approach is unpayable.

In order to improve the behaviour of composite materials and to allow to describe the scatter of the material parameters in a better way, an user-defined model taking into account the influence of strain – rate on failure stress [3] is being developed and will be validated within the next months.

In future, increased computational power will allow to investigate the influence of bird attitude, i.e. the angle between the longitudinal axes of the bird surrogate and the birds velocity vector, scatter in material parameters and scatter in the strength, spacing etc. of adhesives, rivets and bolts.

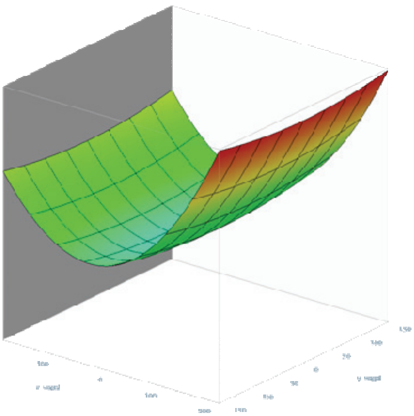

Figure 10: 2^{nd} order polynomial Response Surface generated by LS – OPT for impact site deviation in x – and y – direction

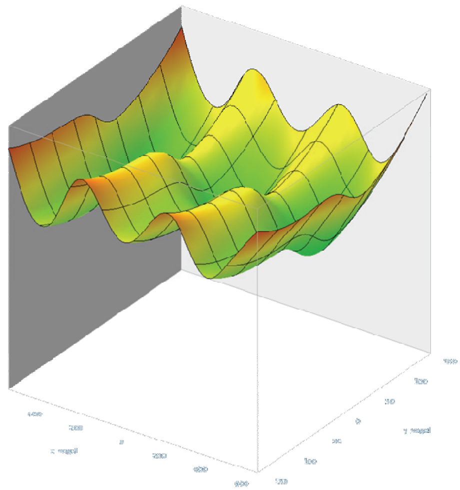

Figure 11: Neural Network Response Surface generated by LS – OPT for impact site deviation in x – and y – direction

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