BIRD STRIKE QUALIFICATION OF THE EXTERNAL STORES OF THE NEW DLR RESEARCH AIRCRAFT HALO

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Abstract

*HALO – the **H**igh **A**ltitude and **LO**ng Range Research Aircraft will be the new DLR aircraft for atmospheric research and earth observation operated for the German Science Community. The external stores for additional scientific equipment comprise Wing Pods as well as a Belly Pod, both have to fulfill bird strike requirements following the JAR Part 25.631 "Bird Strike Damage". The concept development and the design of the structures was performed by applying the explicit crash/high velocity impact (HVI) code PAM-CRASH/PAM-SHOCK in combination with the Smooth Particle Hydrodynamics (PAM-SPH) solver, used to model the bird. The design, analysis, bird strike testing and realization phase for the original HALO external stores nose sections and leading edges were completed at DLR. All parts were adapted to the aircraft structure and are currently in the certification process, followed by the flight testing phase and start of missions in 2010/2011.*

1 General Introduction

HALO – the High Altitude and LOng Range Aircraft will be the new DLR operated Aircraft for atmospheric research and earth observation of the German Science Community. The HALO aircraft is based on a production G550 business jet from Gulfstream Aerospace Cooperation. The aircraft airframe was structurally modified and is currently equipped for specific tasks and will start with first missions in 2010/2011. Among other aircraft modifications and internal installations within the fuselage, it will be equipped with several external structures such as Wing Pods (WP), Particle Measurement Carriers (PMS) under the wings, and under the fuselage a Belly Pod (BP) can be installed. All external stores will carry additional measurement equipment and scientific experiments. HALO will operate as a normal commercial airplane, so all the modifications to the aircraft have to be certified under the JAR Part 25, Extension 14. The external structures and especially the nose sections and their leading edges have to fulfill bird strike requirements following the JAR Part 25.631 "Bird Strike Damage". The BP and the WP nose sections as well as the pylon and Ventral Fin leading edges had to be considered for specific bird strike consideration. It was also decided that all parts are made out of high performance composites comprising glass, carbon or synthetic fibers and polymer resins which are suited for manufacture by infusion techniques. It was intended to use explicit HVI simulation in combination with the SPH from the beginning of the work to develop the bird model, the bird strike design concepts, and also to support the certification route in addition to the bird strike testing.

2 HALO Bird Strike Requirements

The section that is required for bird strike can be found at JAR 25.631 "Bird strike damage":
"The aeroplane must be designed to assure capability of continued safe flight and landing of the aeroplane after impact with a 4 lb bird when the velocity of the aeroplane (relative to the bird along the aeroplane´s flight path) is

equal to V_c at sea level or 0.85 V_c at 2438 m (8000ft), whichever is the more critical. Compliance may be shown by analysis only when based on tests carried out on sufficiently representative structures of similar design."

To obtain the critical case for bird strike certification the relation between the altitude and the Mach number is required. The critical design cruise speed can be taken from the altitude/Mach chart (flight envelope). The critical case is:

Vc = 315,23 KTAS @ sea level, ISA+30
Vc = 162,17 m/s (KTAS) @ sea level, ISA+30

Based on extensive previous experimental investigations, a synthetic bird has been developed by DLR and is used for the tests. This "artificial bird" made of gelatine represents the main parameters that are important for bird strike experiments, Fig 1 shows the artificial bird including the aluminium mould to produce it and the SPH model for numerical simulations:

Mass of the gelatine bird: 4 lbs (1,814 kg)
Density of the gelatine bird: 0,944 g/cm³

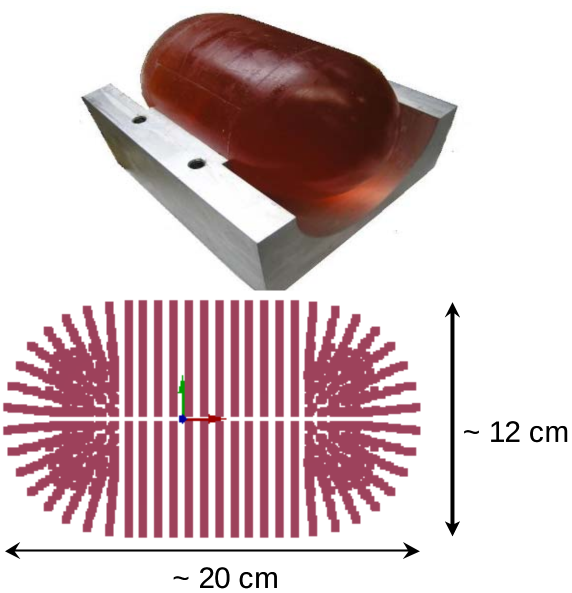


Fig. 1. DLR artificial bird and numerical (SPH) model

In case of bird strike no parts of the external stores may break away and damage primary rear structures. Furthermore flight performance should be maintained and measurement instrumentation protected.

3 Concept Evaluation

3.1 Support by Numerical FE methods

In the HALO project numerical HVI simulations were used systematically from the beginning for the development of the bird strike concepts. Explicit FEM in combination with a gridless particle method allow a variation in geometric details such as designs, laminate thicknesses, composite materials and lay-ups to reduce the time and costs of tests as well as optimization in further design loops. The explicit FE-code PAM-CRASH/PAM-SHOCK and the SPH code PAM-SPH, both provided by ESI GmbH were chosen for the numerical computations [1].

The appropriate material damage models had to be calibrated on the basis of impact tests at the required conditions. In the HALO project those tests consisted of artificial bird strikes on a shell with the X38 nose cap geometry and an aeroengine spinner which were manufactured out of a GFRP/Tegris compound and a pure GFRP laminate respectively. The X38 nose cap shell geometry and the Spinner were chosen because of the geometric similarity to the Belly Pod nose section and the Wing Pod nose section respectively. Fig. 2 shows the correlations of the bird strike test results with the HVI simulations of the X38 nose cap outer GFRP shell. Test and simulations correlated well, also the force-time responses showed good agreement.

3.2 Design Philosophy

The structural concepts for bird strike protection of the external stores had to follow the basic design rule that the impulse forces generated at the load introduction points could be safely taken by the existing fuselage and wing structure of the HALO aircraft. Two different concepts were applied. For the leading edges and the wing pod noses a "splitter"

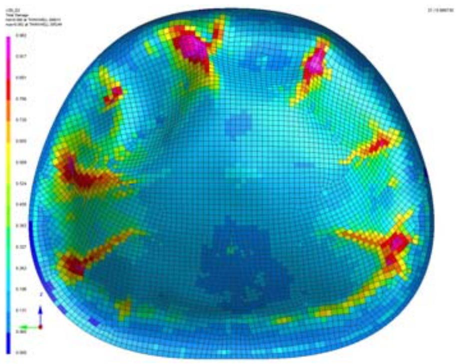
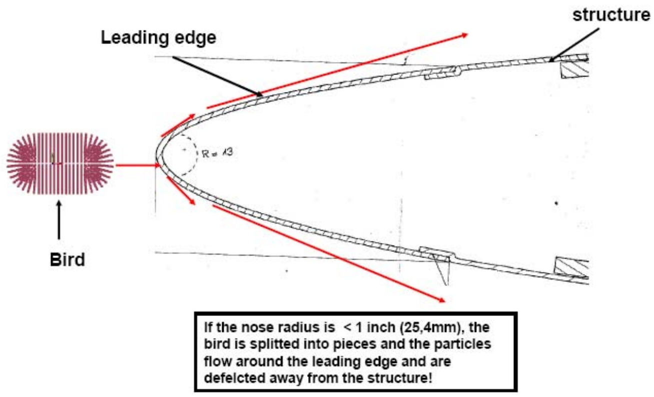
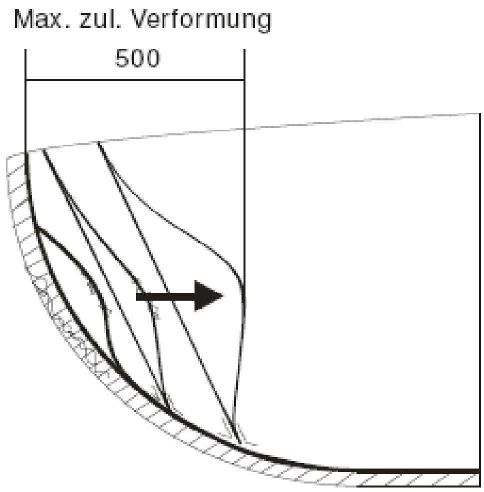


Fig. 2. X38 Nose Cap Outer GFRP Shell – Test (top) and Bird Strike Simulation (bottom)

concept was selected where a strong and stiff structure cuts the bird into parts which are deflected away from the structure. Following a RAE recommendation, this basic concept could be applied for instance to the leading edges where the nose radii are less than 25 mm (1 inch). For the Belly Pod nose section the concept of a deformable outer shell with local fracturing areas in combination with an inner "catching membrane" shell was applied. The large deformation of this inner deformable membrane stops the bird within the fairing structure in a controlled way and limits the transferred loads. It is not allowed that parts of the Belly Pod structure fracture and break off during a bird strike. The Ventral Fin leading edge "Splitter" principle and the "Catching Membrane" for the Belly Pod nose section are shown in Fig. 3.



Splitter Principle



Catching membrane

Fig. 3. Splitter Principle and Catching Membrane for the Leading Edges and the Nose Sections

3.3 Material Selection for the "Catching Membrane"

For technical realization of the "catching membrane", a number of various promising concepts have been developed on the basis of simple flat demonstrator plates and high velocity impacts with a rigid steel ball impactor [2]. Investigated were GFRP laminates with embedded steel ring meshes as catching layer -

a so called ProChain material, GFRP fabric laminates in combination with folded and embedded Dyneema (UHM PE) layers – the so called “tensor skin” concept, and a double shell concept comprising a GFRP outer shell and a catching membrane inside which was made out of a self reinforced polypropylene (PP) fabric, the Tegris material from Milliken/USA. Tegris means: “You are protected”. The examinations of the demonstrator plates with dimension of 300x300mm and about 5mm thickness were compared according to weight and energy absorption criteria.

A plate with 3,2mm thickness made out of Tegris came up with best impact results with respect to mass characteristics. Also the shock resistant GFRP plate (used as reference) has proven good impact behavior. A composite plate comprising GFRP and Tegris combines the properties of stiffness and shock absorbing GFRP with the high deformable self-reinforced PP. The GFRP and Tegris double layer plate, with thickness of 2.5mm respectively and 670g weight caught the steel ball and absorbed an energy of 587 Joule. A photo series of a shot on such a demonstrator plate is shown in Fig. 4, where the impactor penetrates the GFRP laminate and the compacted Tegris layers behind catch the steel ball and stop it.

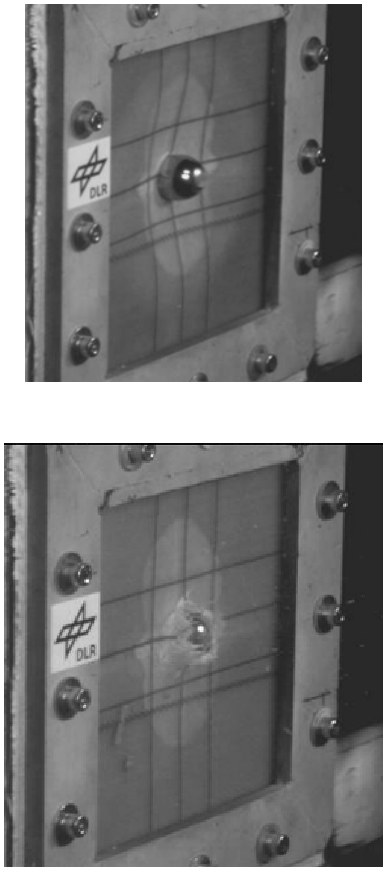


Fig. 4. Shot on a demonstrator plate made of GFRP and Tegris as “Catching Membrane” (300x300x5,1mm)

4 DLR Gas Gun HVI Test Facility

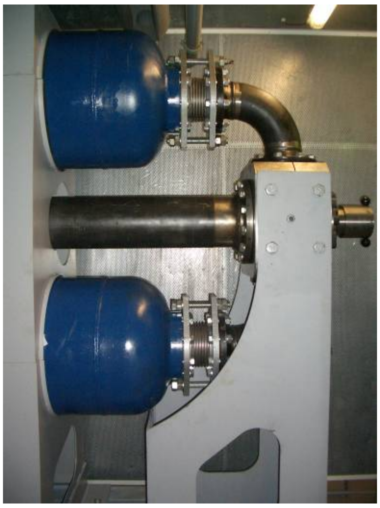
4.1 200 mm Gas Gun – Technical Features

The DLR gas gun test facility comprises three different barrels with different lengths and having different calibers.

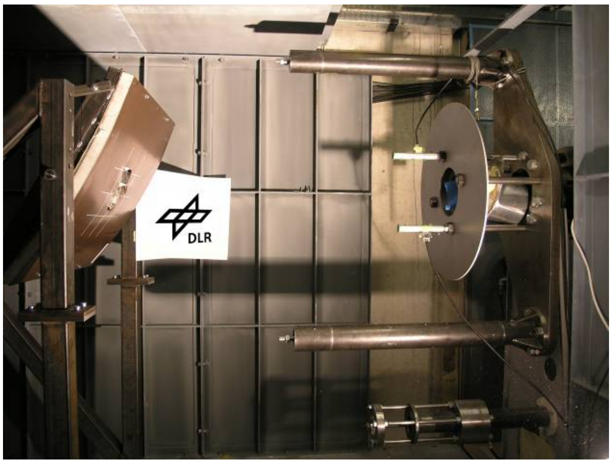
The 200mm gas gun consists of two large pressure tanks that store compressed air connected via two pipe elbows to a breech manifold fitted with a high-speed valve. Opening the valve allows the compressed air to flow into the 200mm caliber by 12m long honed bore barrel and accelerate the projectile. Test shots indicated the required range of velocities up to 250m/s and masses up to 2,5kg could be obtained at pressures below 5 bar. The resulting “payload” equals 0,2 - 2kg.

Fig. 5 gives an overview of the breech, and the muzzle with the sabot stripper and a target of the 200mm gun. All HALO bird strike tests were performed with the 200 mm gun using the artificial bird as was mentioned above.

Sabot Technique: The projectiles are held in sacrificial foam or polystyrene cylinders inserted in spun aluminum alloy ‘cups’. This assembly, called a ‘sabot,’ holds the projectile in the desired orientation and forms a gas seal against the driving gas. A sabot stripper is fitted onto the muzzle of the barrel which restricts the muzzle opening such that the projectile can pass through unimpeded whilst the sabot cannot. The sabot kinetic energy is absorbed by the movement of a heavy steel mass which is connected to the sabot stripper and which could slide forward on the barrel. The cup is destroyed by the sabot stripper by splitting up or buckling in a concertina type folding mode. The same sabot technique is used with the 60mm gun.



Breech

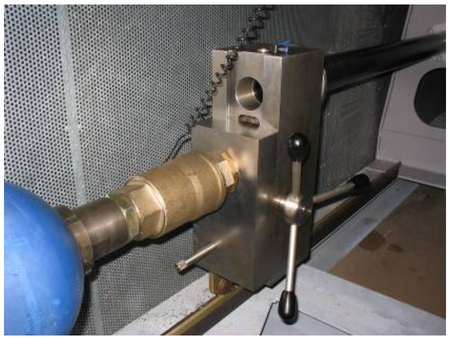


Muzzle with Sabot Stripper and Target

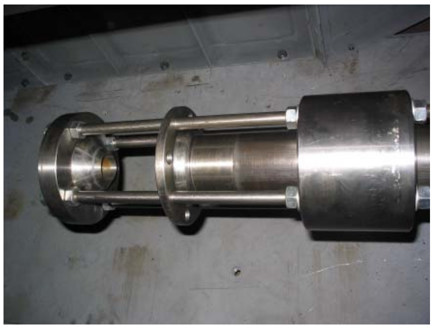
Fig. 5. 200 mm DLR Gas Gun

4.2 The 60 mm Gun – technical Features

The 60 mm gas gun consists of a single 50 liter. pressure tank and a fast acting pneumatic valve to a dove-tail breech and 5m long honed bore barrel, Fig. 6. The impactor masses are considered here to be in the range of 0,01 - 0.5kg with impact speeds up to 250 – 300m/s, depending if air or helium is used as pressurized medium. There are two methods of pressurizing the gun: The automatic system is designed for a maximum working pressure of 8bar; while the manual system enables pressures up to a maximum of 16bar.



Breech mechanism of 60mm gun



Muzzle and sabot stripper

Fig. 6 DLR 60 mm Gas Gun

4.3 The 32/25 mm gas Gun – Technical Features

The 32mm gas gun has a similar design as the 60mm gun with a small 2.25 ltr. pressure tank and 1,8m long honed bore barrel, Fig. 7. A second 25mm caliber tube is available which slides inside the 32mm barrel to reduce the bore and enable standard ´one inch´ hail stones to be launched without sabots. The projectile masses are up to 50g at muzzle speeds of up to 250 - 300m/s, depending if air or helium gas is used. The gun is 'free-standing' and can be placed either in the target chamber of the 200mm gun or on any bench. The gun is pressurized via an automatic pressure regulator giving a maximum working pressure of 8 bar.

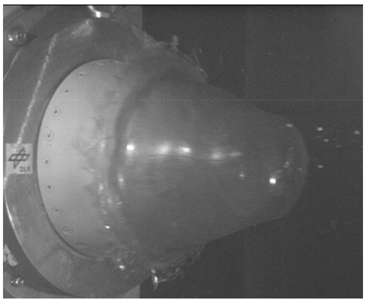
Sabot technique: The 32/25mm guns use a solid plastic sabots which are made out of a cylindrical piece of particle filled thermoplastic PA. A cavity which diameter and depth are adapted to the used projectile in the front of the sabot carries the impactor. The sabot is stopped at the muzzle by a solid steel ring having an appropriate hole for passing the projectile.

Fig. 7 DLR 32/25 mm Gas Gun

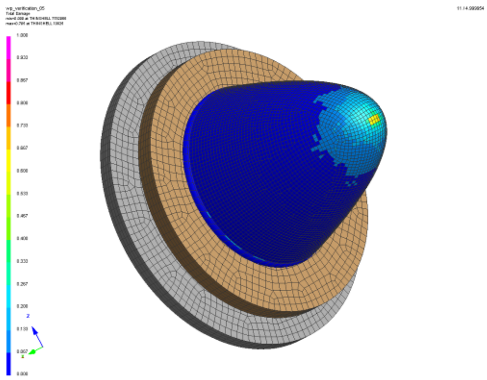
5. HALO Bird Strike Tests and Simulations

5.1 Wing Pod Nose Section

The bird on the nose section was fired in the direction of the symmetry axis of the structure with a measured initial velocity of 160m/s which is about 1.2 percent below the required speed of 162m/s. Fig. 8 shows, how the bird "flows" over the nose section and demonstrates the "splitting" principle. No laminate damage could be observed in the nose structure during test. The simulation however, showed slight damages at the outer laminate layers. The same "splitting" failure mode was observed in the simulation. In the FE model the mounting devices including the clamping plates, frames and the three piezoelectric loads cells were included in the model. The simulated peak contact load and the summarized loads at the load cells in the model were conservative compared to the measurement, i.e. they were predicted about 15 kN higher. The measured peak load at the load cells was about 37 kN. However, the pulse durations correlated very well (test: 1,7 ms; simulation: 2 ms). Also the momentum (force integral over the time) that was transferred to the structure correlated well; the simulation was just 11% higher compared to the test.



Test shot

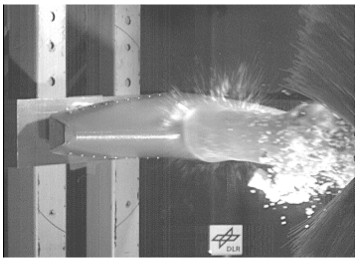


Simulation

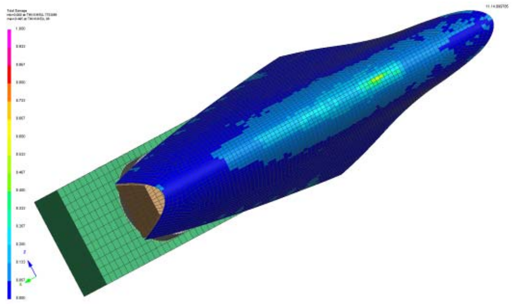
Fig. 8 Bird strike on GFRP Wing Pod nose section,4 lb bird, v_0=160 m/s

5.2 Wing Pod Pylon leading edge

The Pylon leading edge bird strike test has also proven the applied "splitter" principle. The gelatin bird was split along the GFRP leading edge surface and deflected the parts away from the structure, as it was already shown in the simulations. Fig. 9 shows the first contact at the leading edge from test and the beginning of the bird splitting. In the test structure no laminate damage could be observed, whereas the simulation indicated the beginning of slight GFRP ply damage at the surface. The test set up comprised a set of two piezoelectric load cells behind the clamping block of the leading edge. Also, clamping plates and frames were included in the FE model, as was done in the wing pod nose section model. The peak pulse forces in the direction of the bird path were measured at 35 kN, the prediction of the simulation was about 10 kN higher, which is again a conservative result in the sense of certification. The pulse duration of about 2 ms was the same in the test and in the simulation. The momentum of the simulation was just 4 % higher compared to the test.



Test shot – first contact



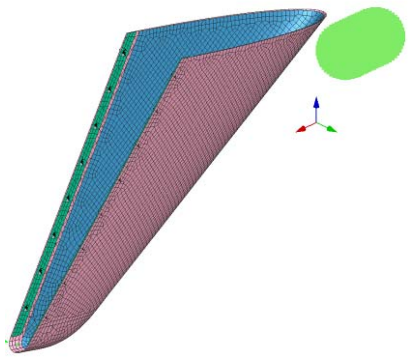
Simulated damage

Fig. 9 Bird strike on GFRP Wing Pod Pylon Leading Edge, 4 lb bird, v_0=165 m/s

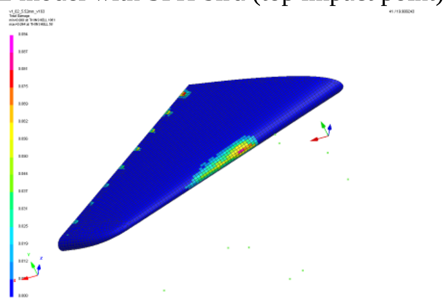
5.3 Ventral Fin Leading Edge

For the bird strike resistance of the Ventral Fin leading edge, also the splitter principle was selected as structural concept. The concept development and the certification route were just performed by bird strike simulations. The confidence for this approach was gained with the test-simulation correlations of the wing pod nose section and the pylon leading edge.

The bird strike simulations with the Ventral Fin leading edge were performed with a 4 lb bird at an impact velocity of 162 m/s. Three different impact locations were selected, one close to the fuselage mounting (top), one in the middle, and one at the lower end of the fin (bottom). All shots were placed in the symmetry plane of the fin in the flight path of the aircraft, which means without any offset or lateral impact angle. The highest maximum response load of 36 kN was simulated at the top impact location, the middle location resulted in a peak load of 32 kN, and the bottom location had a peak load of only 27 kN. The pulse duration in all 3 cases was 2,5 ms. Slight damage could be observed in all shots in the outer GFRP laminate layers, as was the case in the simulations of the Wing Pod nose section and the Pylon leading edge. Fig. 10 shows one of the simulation models and the damage distribution at the middle impact location. The “Splitter” principle for bird strike protection could be demonstrated in all simulation cases. The bird was split into two parts and small pieces and was deflected by the GFRP nose laminate away from the structure into the air.



FE model with SPH bird (top impact point)



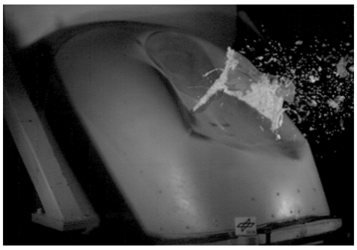
Laminate damage in outer GFRP layers at middle impact location

Fig. 10. Ventral Fin leading edge bird strike simulations

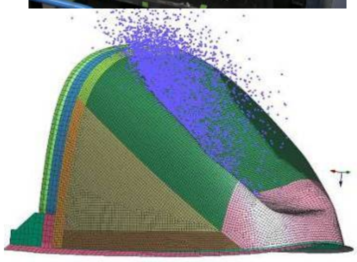
5.4 Belly Pod Nose Section

The bird strike test with the Belly Pod nose section demonstrated well the double shell “catching membrane” principle. The results in Fig. 11 show that the outer shell of GFRP has deformed together with the delaminating inner shell and thereby most of the impact energy was absorbed by a “quasi-plastic” deformation without fracturing. The deformation and de-bonding of the GFRP laminate and the Tegris membrane was as expected during bird impact, whereas the Tegris laminate has performed the greater deformation. The observed failure modes between test and simulation correlated very well. The simulations showed also the critical fracture areas at the bottom of the nose section mounting to the CFRP U-frame of the Belly Pod A-section. The simulated peak reaction forces were at 50kN and the total pulse duration was about 10ms. The bird initial velocity was measured with 163m/s, almost exactly the required impact speed.

Due to the observed damage of the U-frame, the final nose section design had to be modified. However, the effects of the structural modifications were just demonstrated by simulation. Two omega shaped stringers oriented in the y-direction were added to the shell which should stiffen the structure and protect the U-frame from damage. This first solution led to very high peak loads in the clamping area to the fuselage, when a bird impact location close to the fuselage shell was selected. Therefore, in the final design, the front omega stringer was slotted in the x-direction, allowing more deformation in the front part of the nose section and thereby reducing contact forces. The rear omega stringer still protected the U-frame from damage when a low impact point was selected. The final design led to a peak contact force of 52 kN, which is a reduction of 26% compared to the initial modification. The structural modification and the simulated damage mode of the final design are shown in Fig. 12.

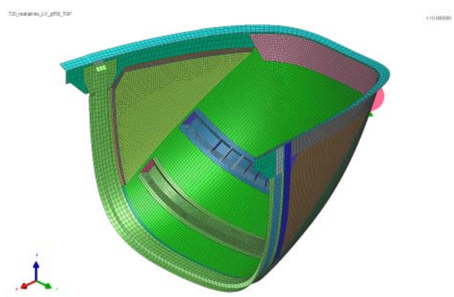


BP test shot and U-frame post test damage

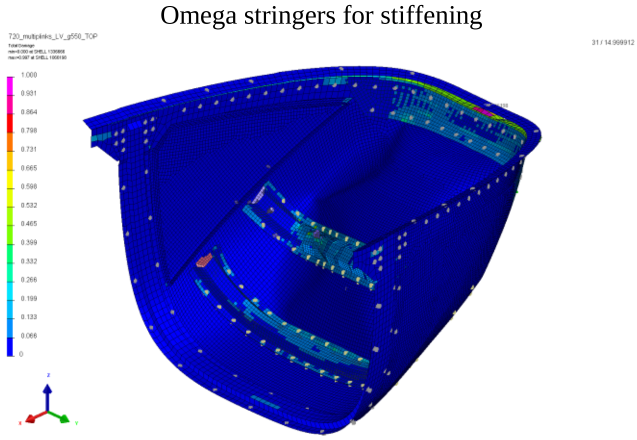


BP simulation

Fig. 11 Bird strike on the double shell of the Belly Pod, 4 lb bird, v_0=163 m/s



Omega stringers for stiffening



Damage mode with omega stringers

Fig. 12 BP structural modifications

6. Summary

The bird strike resistance of the HALO external pods nose sections and leading edges was evaluated and validated in accordance with JAR 25, Extension 14, Section JAR 25.631 "Bird Strike Damage". For the first time at DLR, the conceptual design phase for the structures was fully supported from the beginning by numerical HVI simulation techniques with PAM-CRASH/PAM-SHOCK in combination with PAM-SPH, comprising damage models for the composite parts and a SPH particle model for the artificial bird. The numerical approach was first validated on the basis of bird strike tests with demonstrator structures which showed similarity to the real HALO structures. The improved methodology was later applied to the structural concepts and the dimensioning of the nose sections and leading edges, and also to the preparation of the bird strike tests themselves. A "splitter" and a "catching membrane" principle were applied to absorb the bird kinetic energy and to limit the impulse loads which are transferred to the aircraft structure. The bird strike tests and the numerical results correlated very well with respect to deformation, damage and failure modes and force-time responses. On the basis of the methodology developed with results and expertise gained within the process chain, the HALO External Pod nose sections and leading edges were realized and are currently in the certification phase, and will be ready for flight operation and missions, starting in the year 2010/2011.

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