PRELIMINARY INVESTIGATION ON THE FEASIBILITY OF A BIRD SURROGATE FOR FULL-SCALE BIRD IMPACT TEST

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Abstract

The international safety requirements for aircraft certification prescribe the use of flesh-and-bone birds to demonstrate that the most critical parts of the aircraft are able to withstand a birdstrike and guarantee the so called fly-home capability.

Full scale birdstrike tests carried out with flash-and-bone birds are difficult to perform and most of the time not repeatable. Thus, in an effort to overcome these problems, a number of research and studies have been carried out to develop bird surrogates.

In aircraft industry, bird surrogates are widely diffused and used to preliminarily assess the capability of the structures during their development and to validate numerical model to support and guide the design of new, bird-proof structures.

The aim of the present research work was to assess the feasibility of the jelly projectile made of a commercially available ballistic jelly to be used as a surrogate of real bird in full scale birdstrike tests. This particular jelly tends to maintain its own shape without any auxiliary container; it is easy to use and form, can be re-melted and eventually re-used.

Initially, referring to previous works on this topic, experimental tests were carried out to investigate the impact forces due to the impact of cylindrical projectile onto a rigid target.

In parallel, numerical models of the surrogate bird were created and simulation ran using a proven commercially available code, i.e. LS-Dyna [11]. In this work for the bird modelling the SPH approach was adopted.

The bird models were optimized (with regard to the shape and the constitutive law) and validated referring to analytical solutions, previous results from similar research and bibliographical data about flesh-and-bone bird impacts.

The experimental data were then compared with analytical solution, numerical results and bibliographical data. As a result, the feasibility of the jelly to be use for creating substitute bird was shown.

1 General Introduction

Aircraft certification tests require the use of real birds to demonstrate structure strength in case of impact. However these tests are poorly repeatable. The inability to control real bird orientation and their luck of homogeneity, isotropy and symmetry cause high force variations. It is also very difficult to consider different bird species and their structure. Another issue concerns the luck of hygiene of such tests in laboratory.

To avoid these problems studies about the development of an artificial bird substitute model were conducted and are still in progress 0,0.

A validated bird substitute can be efficiently used both during structures certification then during structures development.

The state-of-the-art bird surrogate was developed by Wilbeck [2],[3] at the end of the sixties, after a huge test campaign carried over with the U.S. Air Force.

More recent experimental results were published by Lavoie 0, while the International

Bird Strike Research Group presented a research about bird surrogate optimal characteristics 0.

The aim of this work is to start the development of a substitute bird model to conduce bird impact real-scale tests using a ballistic gel.

This first development step was focused on the study of impact forces due to the normal impact of cylindrical surrogates on a rigid target.

A direct comparison between Wilbeck results and ballistic jelly impact tests was not possible because of the use of different measurement systems and the lack of an accurate post-processing description.

This problem was solved creating bird numerical models which were validated using bibliographical data about real bird impact.

Real bird impact tests were then correctly simulated throughout the creation of a model of the target and processing numerical data in a suitable way.

Then experimental data were compared to numerical results and bibliographical data, enabling a better comprehension of the phenomena.

2 Experimental Setup

2.1 Bird Surrogate

In this research for creating bird surrogates it was used a synthetic ballistic gel already employed as muscle tissue surrogate to test and compare different types of projectiles and loads.

The features which make interesting the study of this material are:

- the average density (0,80-0,85 g/cm^3) near to that of Wilbeck's surrogate [2];
- the ability to maintain its own shape without auxiliary container which could compromise test results
- a standardized preparation procedure which guarantees good test repeatability;
- the fact that this jelly is readily available and easy to use

Bird surrogates were created following Wilbeck's recommendations.

Bird surrogates (Fig. 1) had two different weight, 0.65 kg and 1.25 kg, and a diameter-to-length ratio (L/D) of 2: 0.65 kg surrogates has a 78 cm diameter; 1.25 kg surrogates has a 98 mm diameter.

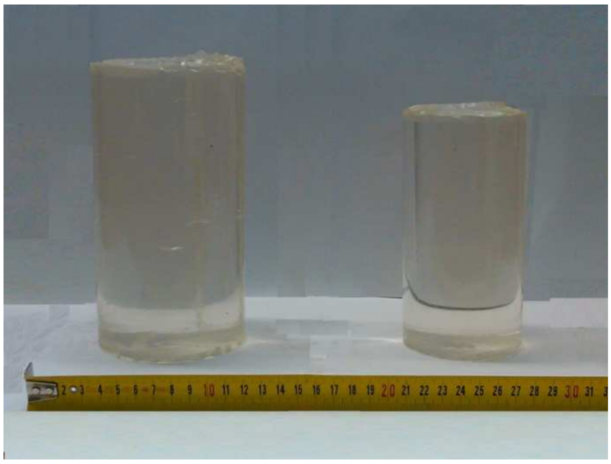


Fig. 1: Jelly projectiles

2.2 Targets and data acquisition

Impact tests were performed using the air gun available at LAST Laboratory of the Politecnico di Milano.

Two different targets were used in the test. The first target (Fig. 2) was a 400x400x30 mm aluminium alloy plate with four axial load cells; the second target (Fig.3) was a 250x200x38 mm steel plate with 2 axial load cells. Load cell signals were sampled at 100 KHz.

Speed was indirectly measured using a Phantom 5.1 high speed camera (8510 frame per second, 512x256 pixel resolution).

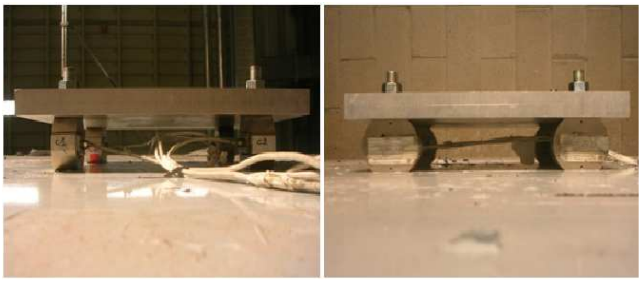


Fig. 2: First target

Fig. 3: Second target

2.3 Experimental results

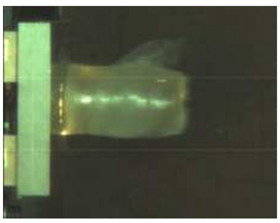
A total of twenty impact tests were performed: eleven with 0.65 kg projectiles; and nice with 1.25 kg projectiles.

Impact speed was between 100 and 170 m/s while projectiles L/D ratio was between 2 and 3.

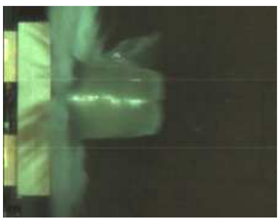
A first important results was that the jelly maintained his own shape and the tests results were consistent.

The trajectory of the bird surrogate was perpendicular to the target at the beginning of the impact (Fig.4a). The jelly flew in the air like a bubble of water until hit the target (Fig.4b and Fig.4c).

High speed videos allowed to investigate the dynamic of the projectile. The four impact phase described by the hydrodynamic theory [10] are apparent in Fig. 4.



a) Impact



b) 0,235 ms after impact

c) 0,70 ms after impact

d) 2,35 ms after impact

Fig. 4: Impact of a 0,65kg projectiles at 124 m/s against the second target

2.4 Comparison with bibliographical data

Impact forces data from tests were compared to bibliographical data from Barber and Wilbeck [2] although the performed tests were influenced by dynamic response of the measurement system and therefore it was necessary to filter data using with a CFC600 filter.

The experimental data were converted into a dimensionless form. Using the first target the maximum dimensionless force was about 2.2 higher than in Wilbeck's tests (Fig.5); using the second target it was 1.5 higher (Fig.6).

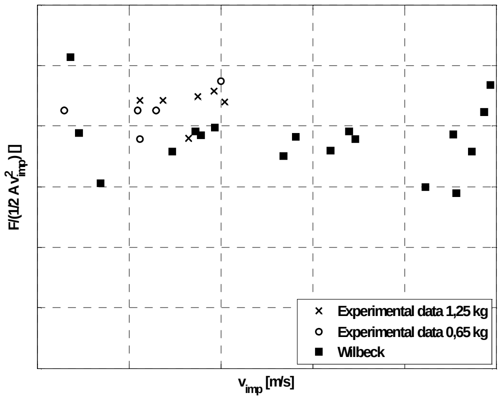


Fig. 5: Non-dimensional peak force on first target

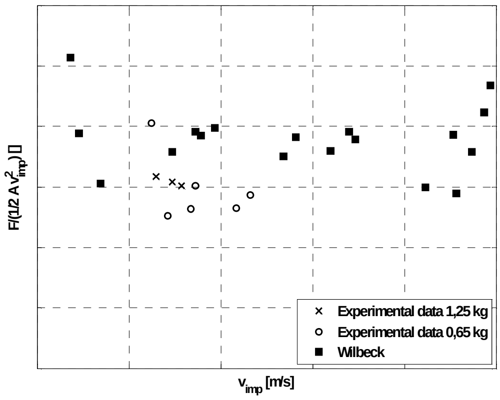


Fig. 6: Non-dimensional peak force on second target

The result were deemed encouraging although not completely satisfactory

On the other hand it should be remarked that there are many variables involved in the phenomena that make comparisons difficult.

Anyway, there are elements to state that the jelly used in the tests is suitable to develop a bird surrogate model.

From this point of view, further researches are needed to improve surrogate creation using more accurately real bird impact.

3. Numerical model development

Numerical models were created to compare experimental tests with a validated bird model impacting against a target model.

Bird numerical model was validated using Wilbeck data [2]. Non-linear explicit finite elements code LS-Dyna was used for the numerical simulations.

3.1 Bird model creation and validation

Bird model was created using a Smooth Particles Hydrodynamics (SPH) approach.

SPH models are widely studied in literature and are suitable for bird impact analysis.

Material model density is 0,95 g/cm^3 and the material has a polynomial equation of state that includes the effect of porosity at 15%VF.

Different model geometries were used to account of the differences in shape of the surrogate and real bird (Fig.7).

A cylindrical model is more appropriate to reproduced ballistic jelly projectiles impact, while a elliptical model is suitable to simulate a real bird impact.

Different L/D ratios were used to take into account projectiles lengthening.

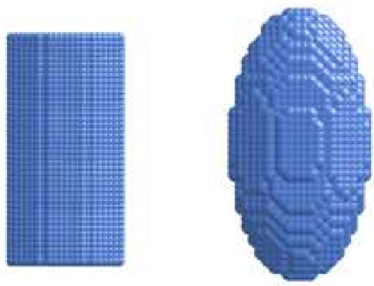


Fig. 7: SPH bird models

Numerical results were assessed with regard to impact pressures and forces referring to test data of birdstrike against rigid targets [3] and to the hydrodynamic theory (Fig. 8).

Numerical data were sampled at 1 MHz and then filtered at 50 kHz, taking into account of the sensor bandwidth.

Pressure values agree with bibliographical data both about Hugoniot pressure (Fig. 9) and about stagnation pressure (Fig. 10).

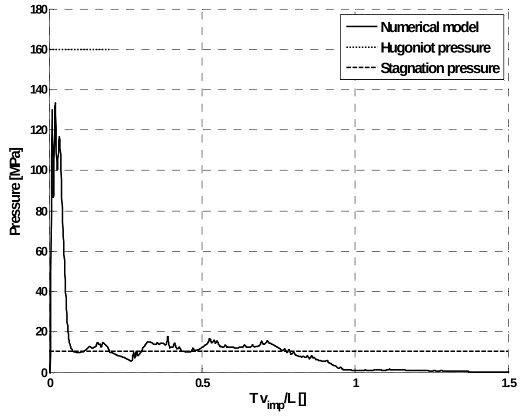


Fig. 8: Comparison between pressure on target of cylindrical model and theoretical results

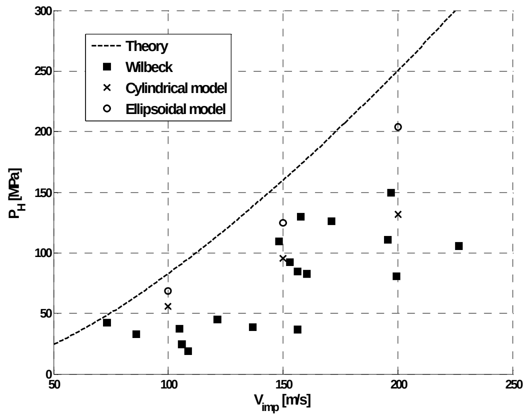


Fig. 9: Hugoniot pressure comparison between experimental data and numerical results

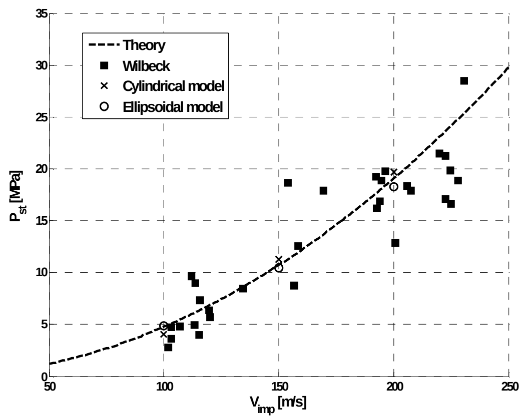


Fig. 10: Stagnation pressure comparison between experimental data and numerical results

Impact force analysis shows how the ellipsoidal shape is more suitable to reproduce a real bird impact (Fig. 13) whilst the cylindrical shape leads to force peak higher than predicted by the hydrodynamic theory (Fig. 12). Despite of this, the ellipsoidal shape may overestimate maximum force in comparison to Wilbeck's test data (Fig. 11).

In view of these results, the bird model was deemed suitable for being used for a further comparison with test data obtained using the bird surrogate developed in this research.

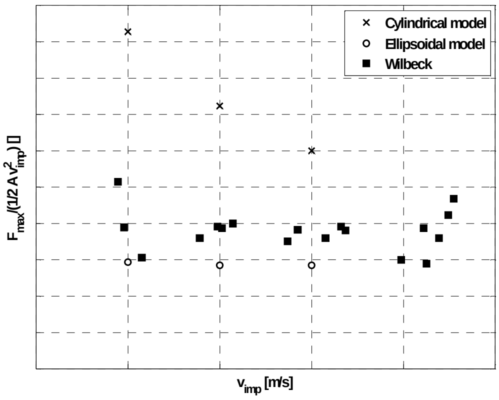


Fig. 11: Comparison of non-dimensional peak force between Wilbeck data and numerical models results

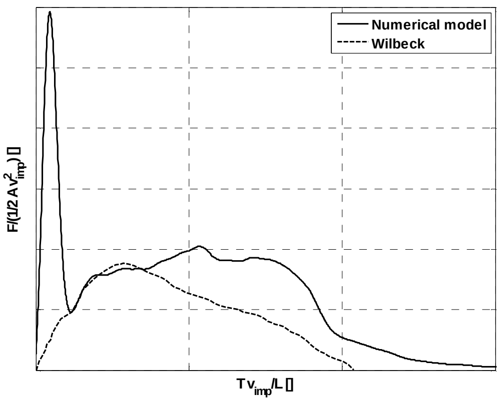


Fig. 5: Force comparison between cylindrical model and real bird

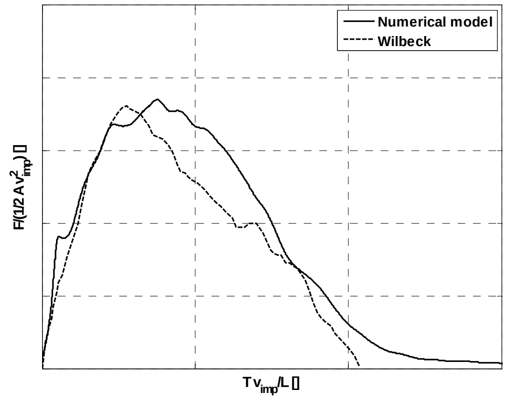


Fig. 63: Force comparison between ellipsoidal model and real bird

3.2 Target modelling

The first and the second target plates were modelled using solid elements, while 1mm thick shell elements on the impact surfaces were used to increase contact algorithm working.

Load cells were modelled using discrete spring elements.

In the model of the second target a simple mass-spring model of the support was added.

Thus, the first target model has only an 800 Hz vibration mode, while the second target model has a further 9 kHz vibration mode.

3.3 Comparison between experimental data and numerical results

Experimental data were compared with results from numerical models validated using Wilbeck results.

Projectiles deformation (Fig.14) shows how ballistic jelly behaviour is good and in accordance to numerical validated models.

Only in Fig.14b and Fig.14c bird surrogate shows a higher radial acceleration.

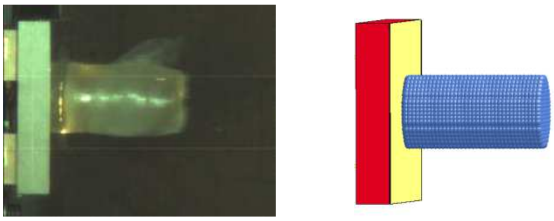
A good correlation emerged by comparison between ballistic jelly experimental force data and numerical results.

Impact force on targets was affected by measurement system dynamic response, but this phenomenon was adequately reproduced by numerical models.

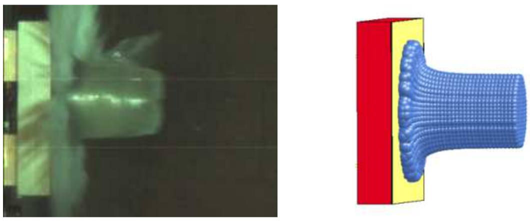
This result, shown by force history in Fig.15 and Fig.18, demonstrated that targets numerical models were suitable for our analysis, although they are very simple.

Higher bandwidth load cell used on the second target increased allowed to analyse higher frequencies.

Initial peak force showed by cylindrical models against rigid target is not present during experimental test, because the impact and the measurement system are not ideal (Fig.15).



a) Impact



b) 0,235 ms after impact

c) 0,70 ms after impact

d) 2,35 ms after impact

Fig. 14: Comparison between numerical and experimental deformation, 0,65 kg bird surrogate, speed 124 m/s.

Thus, for jelly projectiles the cylindrical shape was an disadvantage considering other models which better reproduce real birds impacts, as elliptical ones (Fig. 18).

Comparing the peak load variation at different impact speeds, a good agreement can be observed between experimental data and numerical model with L/D ratios ranging from 2 to 3 as seen on Fig. 16, Fig. 17, Fig. 19 and Fig. 20.

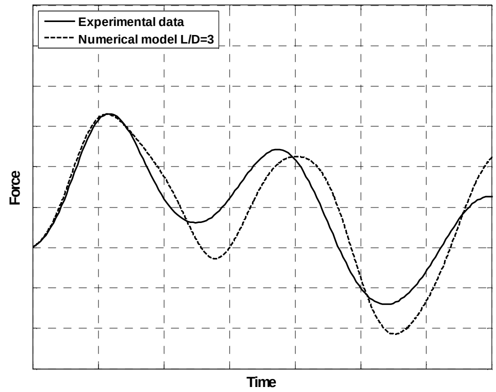


Fig. 15: Comparison of force on 1st target between experimental data and cylindrical model results, 1,25 kg surrogate, speed 125 m/s, L/D=3

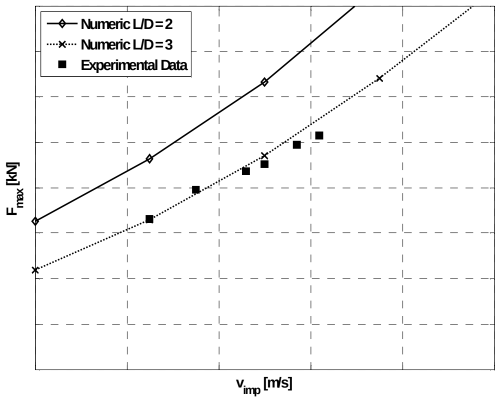


Fig. 16: Peak force on 1st target, 1,25 kg bird surrogates, cylindrical model

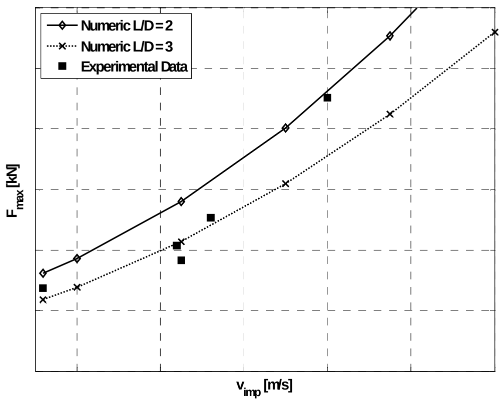


Fig. 17: Peak force on 1st target, 0,65 kg bird surrogates, cylindrical model

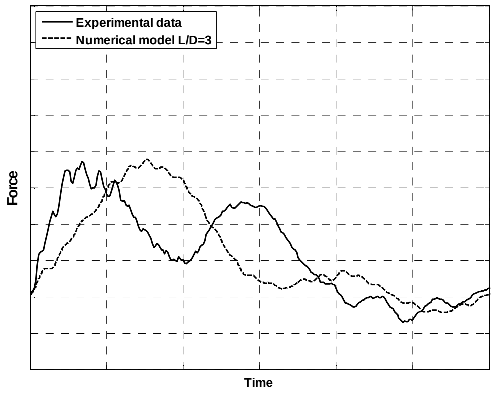


Fig. 18: Comparison of force on 2nd target between experimental data and elliptical model results, 0,65 kg surrogate, speed 167 m/s, L/D=2.5

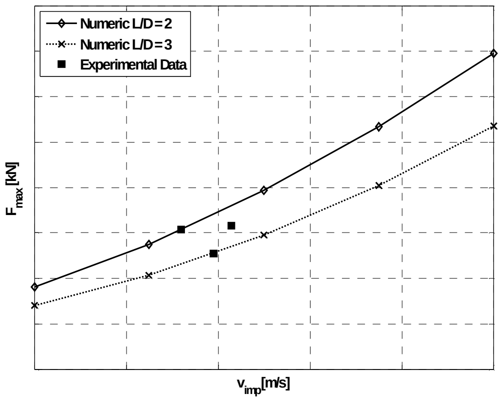


Fig. 19: Peak force on 2nd target, 1,25 kg bird surrogates, cylindrical model

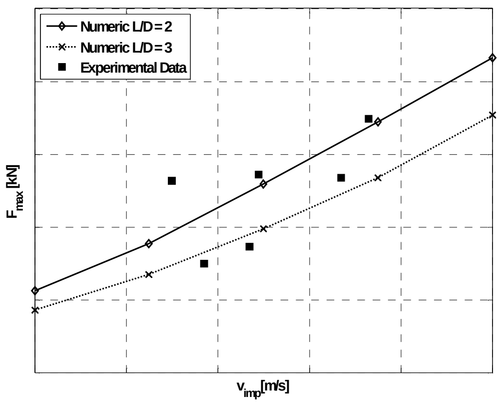


Fig. 20 : Peak force on 2nd target, 0,65 kg bird surrogates, cylindrical model

The L/D variation on the numerical models has been introduced to take into account the different states of deformation and lengthening of initially identical ballistic jelly projectiles after being released by the gun barrel.

Considering the impact force peak (Figg. 15-16-17) the cylindrical shape provide a better representation of the test data than the elliptical one (Figg 18-19-20).

This result confirms the behaviour highlighted by high speed camera videos (Fig.14): the jelly surrogate maintains the cylindrical shape and this led impact force on the target different from those that characterise a real bird impact.

Conclusion

In this research work a ballistic jelly projectile was assessed to be used as a surrogate of real bird in full scale birdstrike tests.

Experimental tests on projectiles normal impact were carried out and numerical simulations on validated bird numerical models were performed too.

Experimental data were compared both to Wilbeck bibliographical results and numerical simulations in order to have a full comprehension of the behaviour of the ballistic jelly compared to real birds.

The result is that the material is suitable to create substitute bird models for normal impact tests. The ballistic jelly used in this research confirms all the characteristics that made it an interesting material in bird impact studies and can be used to the creation of a bird substitute.

Further investigations should be carried out before using ballistic gel projectiles as real bird substitutes, at least in structures development studies.

To achieve this result, a direct comparison between experimental data and real bird tests will be essential.

Characterisation of the material used for the target must be deepen using static and dynamic characterization tests and investigating temperature influence on impact forces.

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