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Dynamic Response Mesurement during the High-Speed Impact

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Abstract. The material of the aircraft structure must resist to the high-speed impact – it means the impact of the bird or of the hail at the flight speed (bird-strike or hail-strike). Proof of this resistance can be made by experimental or by the numerical way. The recent development of the numerical methods takes advantage of the numerical way. However, the necessity to verify used numerical models creates new challenges on the experiments. The goal is to measure and to record a great deal of data during the very short time of the high-speed impact.

Use of the high-speed load cells makes possible to record the time-dependent force response of the impact event. However, the major difficulty of this approach is the existence of the parasitic resonances. The objective of the stand design is therefore to minimize these parasitic resonances, due to the stand structure dynamics.

In this way, the special equipment for the experimental research of the dynamic response during the high-speed impact was designed and realized. The stand is destined to support the specimen within impact of projectile (bird or hail) ejected from the pneumatic gun. The dynamic response measurement is realized by means of load cells.

Introduction

Airworthiness requirements claim the resistance of the aircraft structures to the high-speed impact – it means the impact of the bird or of the hail at the flight speed (bird-strike or hail-strike). Proof of this resistance can be made by experimental or by numerical way. The recent development of the numerical methods, especially the explicit solution of the finite element method, takes advantage of the numerical way. However, the necessity to verify used numerical models – particularly the model of the material damage and the constitutive model of the impact body (projectile) – creates the new challenges on the experiments. The goal is to measure and to record the great deal of data during the very short time of the high-speed impact. This is technically difficult, but necessary for the numerical models verification.

Use of the high-speed load cells makes possible to record the time-dependent force response of the impact event. However, the major difficulty of this approach is the existence of the parasitic resonances. The experimental stand, the support of the studied specimen, has the eigen dynamic response and in consequence, the final measured dynamic response is coupled with the stand structure one. The objective of the stand design was therefore to minimize these parasitic resonances, due to the stand structure dynamics. For this reason, at the first draught, the equipment was optimized by means of FEM numerical simulations.

Specimen

The experimental stand was designed for the large flat panels, convenient for the advanced developmental experiments. Disadvantage of the standard square (or rectangle) specimen form is the risk of the non-regular flaws (see fig.1) [2]. The specimen is typically over-loaded at the centers of the edges – risk of the cracks and the disruption –, the specific form damages can appear at the corners. To avoid these types of flaws, the optimal specimen form is the circle. For the technological reasons, the octahedron was adopted (see fig. 2).

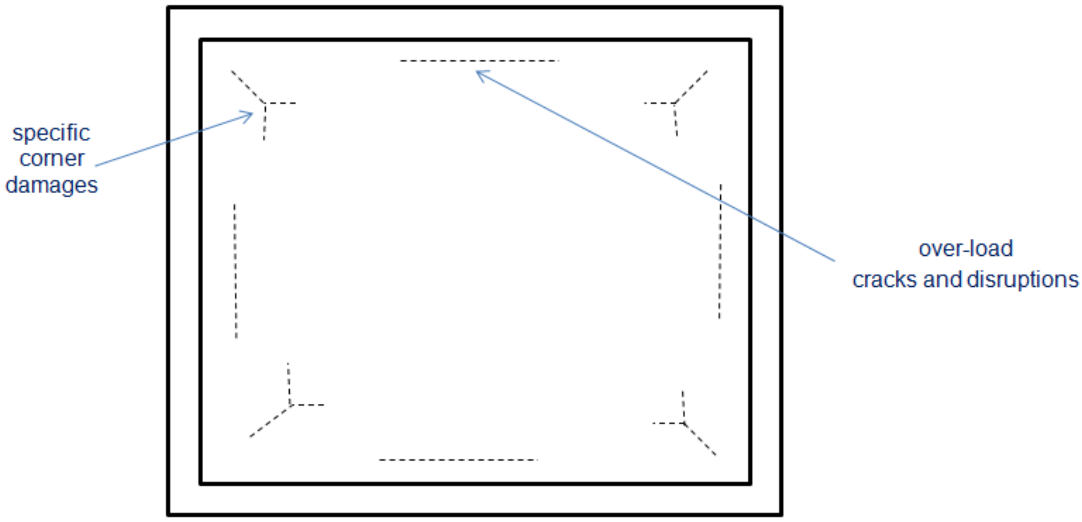

Fig. 1: Typical non-regulars flaws of the standard square form specimen

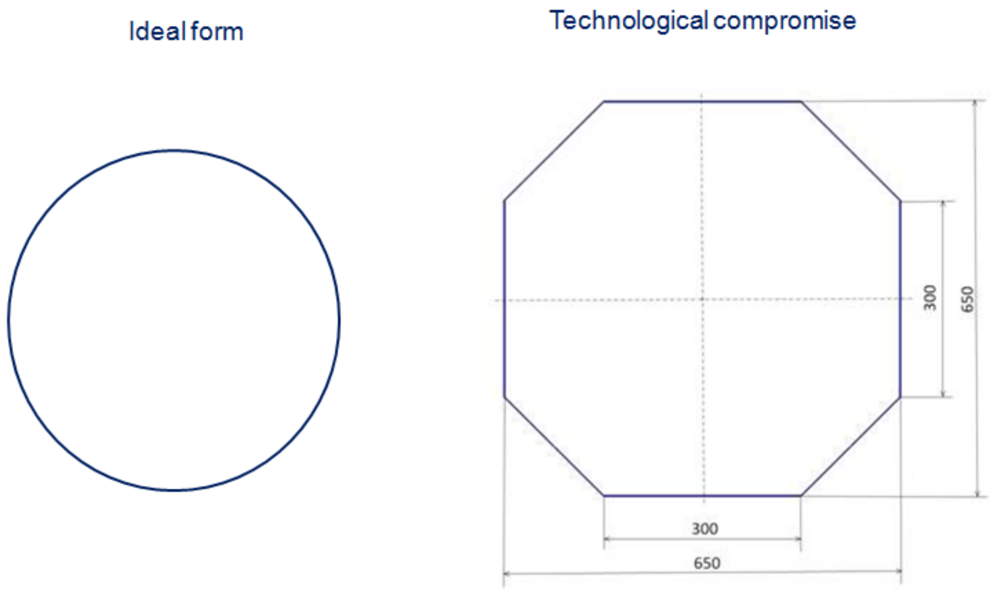

Fig. 2: Optimised specimen form

Experimental stand conception

Three basic objectives were applied for the equipment design. At first, the stand is destined to support the specimen within impact of projectile (bird or hail) ejected from the pneumatic gun. Secondly, the equipment is adapted to the dynamic response measurement and recording by means of load cells.

At last, the stand design enables the impact in any angle (from 0° to 90°), without change of the first contact point. It means, that in all cases, the gun axis points at the centre of the specimen. For any impact angle, the first contact of the bird or of the hail with the specimen occurs in his centre.

For this reason, the stand structure is divided in two parts. The movable part is connecting with the fixed one by means of pivots placed in the plane of the specimen (see fig. 3). In consequence, the gun axis points always at the same point, at the centre of the specimen [4].

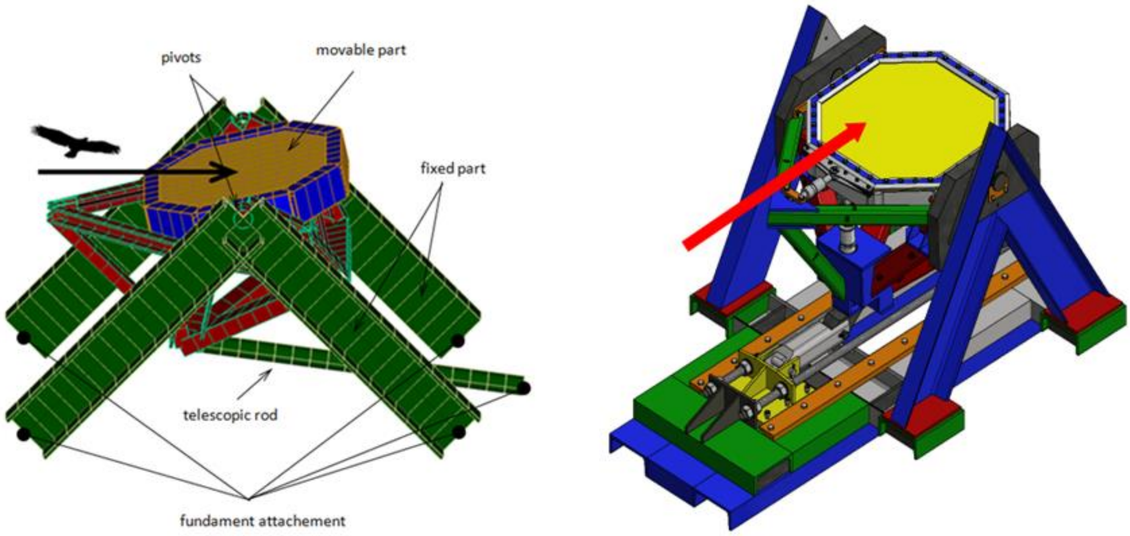

Fig. 3: Experimental stand configuration for low-angel impact [3], [4]

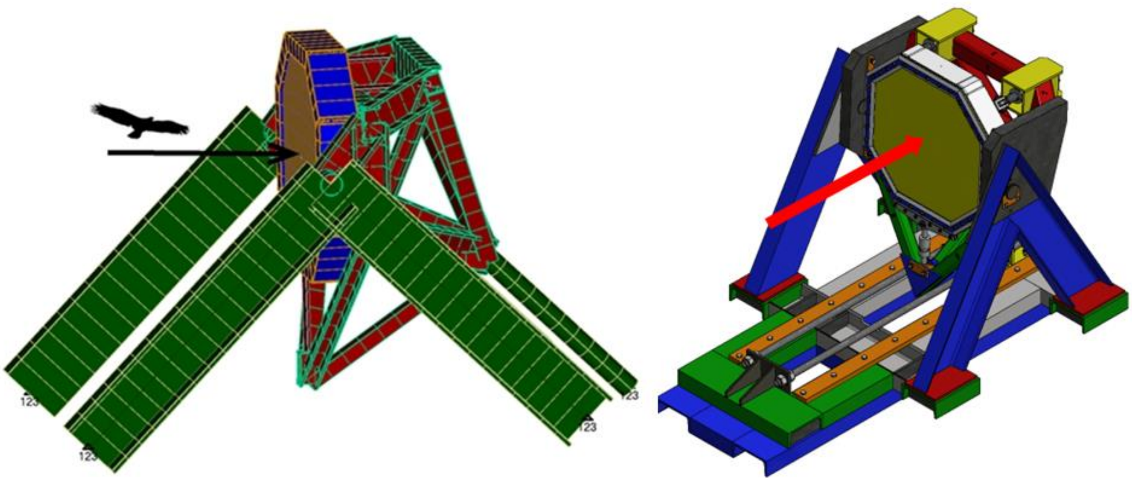

Fig.4: Experimental stand configuration for perpendicular impact [3], [4]

The impact angle is controlled on principle by the telescopic rod. As is demonstrated on the fig. 3, if the telescopic rod is prolonged, the impact angle decreases. By contrast, the short telescopic rod gives the large impact angle. On the fig. 4, the case of the perpendicular impact is demonstrated. The real, detailed design is a little different (see the right parts of the fig. 3 and of the fig. 4) [3]

Numerical simulation and optimisation

The major difficulty of the time-dependent force response measurement during impact event, by means of high-speed load cells, is the existence of the parasitic resonances. [3] The experimental stand has the eigen dynamic response and in consequence, the final measured dynamic response is coupled with the stand structure one. For this reason, the minimization of these parasitic resonances was a priority objective.

At the first draught, to detailed design, the FEM numerical simulations were applied. The finite element model was loaded by the time-dependent force function, simulating the contact interaction between the projectile (bird or hail) and the specimen. The number of appropriate force functions was deduced by an analytical way (with some arbitrary assumptions), by an empirical way (experimental results) and by a numerical simulations (explicit FEM solution, liquid like bird model). [5]

The time-dependent force function, applied on the complete structure model (specimen, stand structure and load cells model) cause a dynamic response. The dynamic behavior is analyzed by means of numerical FE simulation. The essential result is the time-dependent virtual load cells record – it means the computed internal force of the FE elements, simulating the load cells. In the ideal case, the stand structure parasitic resonances are completely negligeable and in consequence, the virtual load cells record corresponds to the applied force via equilibrium conditions. In the real case, the deviations from the equilibrium condition are incurred by the parasitic resonances influence. The goal of the optimization is to minimize, as much as possible, the parasitic resonances for all applied force functions. [1]

The example, demonstrated on the fig. 5, shows the case of the force applied in the specimen plane (the force due to the friction between the projectile and the specimen in case of small angle impact). Theoretically, only one load cell is loaded. According to the equilibrium condition, the load of this load cell is equal to the applied force.

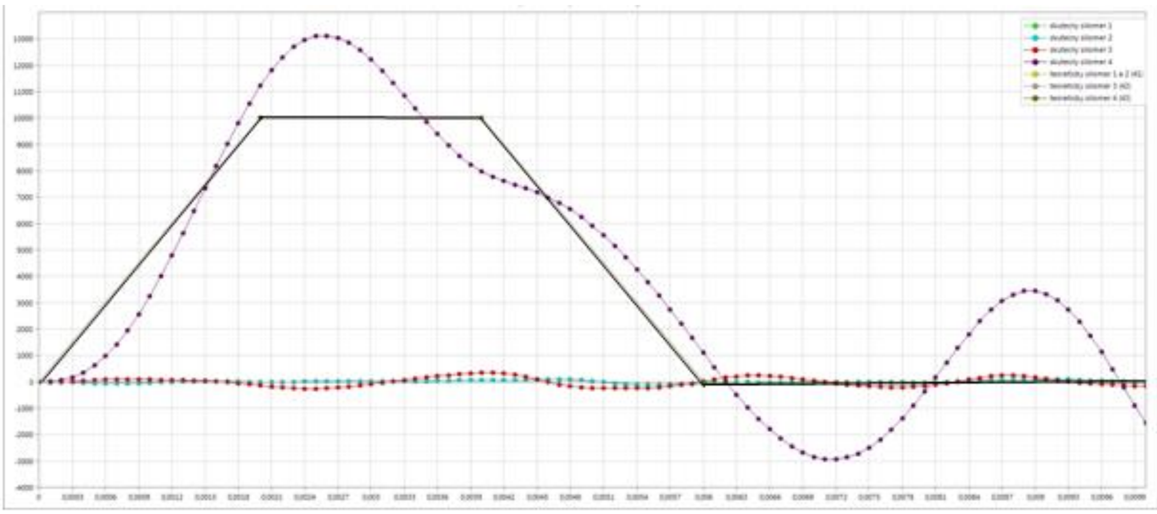

Fig.5: Example of the virtual load cells records – in specimen plane applied force [3]

As is observed on the fig. 5, the applied force (black solid line) is not exactly equal to the virtual load cell record. The applied force function has a trapezoid form, after the short impact pulse, the applied force is zero. The virtual load cell record oscillates arround the applied force function. This deviations are relatively important, however, the oscillations at only one dominant frequency are easy to eliminate by filtration. The virtual records of other load cells are very close to the theoretical value, very close to zero.

Conclusions

The special experimental equipment for the research of the dynamic response during the high-speed impact, was designed, developed and realized. The challenge was to measure and to record the great deal of data during the very short time of the high-speed impact, useful for the complex numerical model verification.

The stand was destined to support the specimen during impact of projectile (bird or hail) ejected from the pneumatic gun. The specimen is defined by the large flat panel with the special octahedron form, to avoid the non-regular flaws. The stand design enables the impact in any angle (from 0° to 90°), without change of the contact point. Independently on the impact angle setting, the gun axis points always at the same point, at the centre of the specimen.

The dynamic response measurement is realized by means of load cells. At the first draught, to detailed design, the equipment was designed and optimized by means of FEM numerical simulations in objective to minimize the parasitic resonances of the stand structure.

References

[1] R. Doubrava, M. Oberthor, P. Bělský, M. Dvořák, K. Doubrava, Experimental Verification of Jet Engine Composite Inlet for Bird and Hail Impact Resistance, Conference proceeding of 56th konference on experimental stress analysis (EAN 2018), ISBN 978-80-270-4062-9

[2] R. Doubrava, M. Oberthor, P. Bělský, J. Raška, Bird and hail impact resistance analysis on jet engine composite air inlet, MATEC Web Conf. Volume 188, 2018, Art. No. 04006, DOI: https://doi.org/10.1051/matecconf/201818804006

[3] R. Doubrava, M. Oberthor, P. Bělský, O. Vích, An Improvement of measurement technique for high speed impact tests analysis, EAN 2019 Conference Proceedings ISBN 978-80-214-5753-9

[4] J. Raška, Numerické simulace měřící soustavy pro vysokorychlostní impakty a výpočtové ověření návrhu zkušebního zařízení pro výzkum dynamické odezvy, VZLÚ report R-6656, 2016

[5] R. Hedayati, M. Sadighi, Bird Strike An Experimental, Theoretical, and Numerical Investigation, ISBN: 978-0-08-100093-9, Elsevir Ltd 2016

[6] K. Hyonny, Impact Damage Formation on Composite Aircraft Structures, UCSD Federal Aviation Administration JAMS Paper,2014