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BIRD IMPACT ON AIRFRAMES: A PYROTECHNICAL PROJECTILE LAUNCHER

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Abstract

When developing forward-facing aircraft parts and especially leading edges, the bird impact problem appears to be one of the key topics. The way the designed elements withstand that impact has been studied for many years, but now that composite materials are more than ever considered to replace metal alloys, computer simulations have to be validated once again by means of experimental firings.

This paper presents an experimental pyrotechnical set-up developed by the Weapon systems and Ballistics Department of the Royal Military Academy with active participation of SONACA S.A.. A 20 mm gun is connected to a 160 mm barrel by means of a conical interface. The combustion gasses from a 20 mm "blank" round accelerate a projectile made of a polyurethane cylindrical sabot and an egg-shaped impactor.

The gelatine impactor simulates a 1.8 kg bird according to both European and American regulations.

Velocities of the impactor currently approach 150 m/s; ongoing work is trying to achieve 180 m/s. The initial sabot configuration was redesigned to ensure better air tightness while withstanding the pressure build up. Different 160 mm barrel lengths were experimented to obtain maximum muzzle velocity. Initial positioning of the projectile in the barrel was optimized for smoothness of pressure build up against the rear face of the container. Last but not least, the conical interface was dimensioned by means of Computational Fluid Dynamics (CFD) software to reduce losses and optimize energy transfer to the projectile.

BIRD THREAT

Bird impact versus bird ingestion

The very first recorded casualty due to a bird strike goes back to 1912, when the pilot died after his plane hit a gull and crashed into the sea close to the Californian coast.

Since then, the number of reported bird strikes has considerably been increasing. Available data show that more than 223 people have been killed worldwide in civil-aircraft accidents caused by bird strikes. In addition, a minimum of 63 aircraft have been lost as a result of bird strike related accidents. In military aviation, more than 353 serious accidents have been documented since 1950, including a minimum of 165 fatalities [1].

In 2002, the US authorities reported more than 6100 bird strikes to civilian aircraft while the military aircraft were hit 3700 times [2].

A collision against a passive part of the airplane - windscreen or canopy, leading edge of wing or empennage – is generally designated by bird impact, whereas bird ingestion is related to a bird hitting an engine.

The vast majority of bird impacts occur during take-off or final approach phase of the flight.

Legal requirements

In order to ensure flight safety in front of this threat, the European and American authorities have worked out a set of regulations forcing the manufacturer to adopt various measures. As far as bird ingestion is concerned, the engines have to shut down safely after striking an eight pound bird. In case of bird strike on airframe parts like wings or fuselage, the Federal Aviation Administration and the European Joint Aviation Authority require the aircraft to be *able to safely complete a flight after striking a four pound bird at design cruise speed* [3]

Certification and development

In terms of bird impact on the airframe, the manufacturer needs to have his element certified according to these regulations. The assessment by the authorities is often made by trials firing a freshly killed 1,8 kg chicken at the wing element.

To avoid - or at least strongly reduce - firings with these chickens, manufacturers have initiated the use of equivalent materials. Gelatine is a common used surrogate, cheap, easy to produce and non toxic.

SURROGATE LAUNCHING

Principle

To accelerate the surrogate up to the required velocity, typically 150 to 180 m/s, many test centres use pneumatic launchers, requiring considerable volumes of pressurized gas and rather long barrels. In order to increase flexibility of the launch, a pyrotechnical launcher was designed and built by the Weapon system and Ballistics Department of the Royal Military Academy in Brussels.

The general setup is sketched in figure 1.

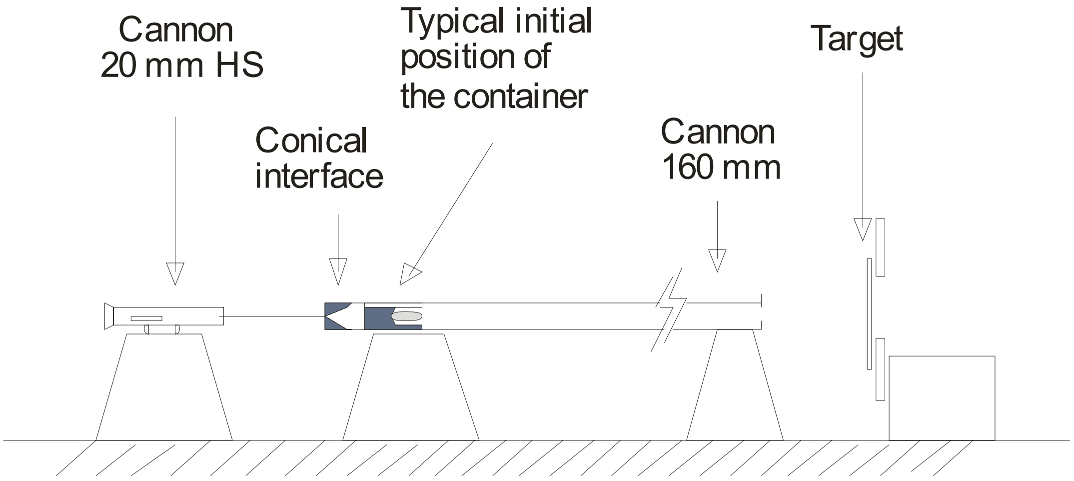

Figure 1 : General setup

A 20 mm Hispano-Suiza gun is connected to a 160 mm calibre barrel by means of a conical interface. The combustion gases from a 20 mm blank round accelerate a projectile made of polyurethane (PU) cylindrical sabot and an egg-shaped gelatine impactor. Figure 2 represents the projectile.

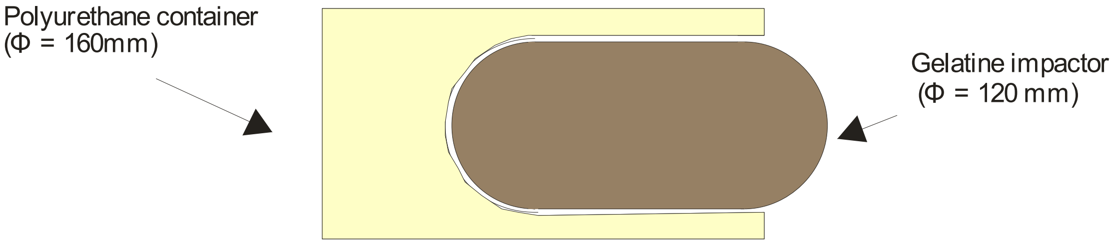

Figure 2 : The projectile

Problems encountered during development

During the development of the pyrotechnical launcher, several problems were encountered.

The in-bore survival of the container was the first one. Due to the high pressure at its rear face, the container disintegrated in the barrel and came out of the launcher in a cloud of PU fragments. The remedial actions were to have a 2 mm steel disc bonded onto the rear face of the container to absorb the high pressure rate, and the application of a fibreglass coating to the exterior surface of the container. This increased its resistance to fracturing

The second difficulty to address was the lack of air tightness of the container. Gases were seen on the high speed videos emerging from the muzzle before the projectile. To stop this loss of energy, a rubber disc was inserted between the rear face of the container and the steel disc. When the pressure wave hit the steel disc, the rubber disc was compressed and dilated radially to ensure obturation in the barrel. Subsequent videos showed no more gas leaking forward of the projectile.

The third problem was the survival of the gelatine impactor itself: it initially did not resist the strong forces it underwent during acceleration in the barrel. A first action was to increase the barrel length, replacing the initial one metre barrel by a five metre one. Simultaneously, the container was positioned at about two metres from the conical interface in order to reduce the initial acceleration. Injecting methylene blue in one of the impactors revealed that the very rough PU debris from the disintegrating container scratched the gelatine projectile during in-bore motion, leading to its tearing. A fibreglass coating therefore was also applied to the internal surface of the cylindrical container. As this still did not solve the problem, higher density gelatine was used, resulting in successful survival of the projectile.

Obtaining the requested velocity level was another problem. Experiments were conducted with different propellants, achieving a maximum pressure of about 68 MPa [4]. The latest firings were all performed with the cartridge case filled with a mix of 7g blank powder, chosen for its high combustion velocity, and 22g spherical ball powder. This combination achieved muzzle velocities up to 150 m/s with a container mass of about 1300g and an impactor weighing 1800g.

OPTIMIZATION OF THE CONICAL INTERFACE

The initial conical interface

In order to reduce losses and achieve ideal energy transfer between the 20mm and the 160mm barrel, simulations were made with a Computational Fluid Dynamics (CFD) software package to design the optimal cone opening angle.

Figure 3 shows a close-up of the original conical interface. In the upper part, two drilled holes for pressure transducers can be seen (1 and 2), while the upper right hand side displays the housing (3) for an o-ring, designed to avoid flowing back of the combustion gases.

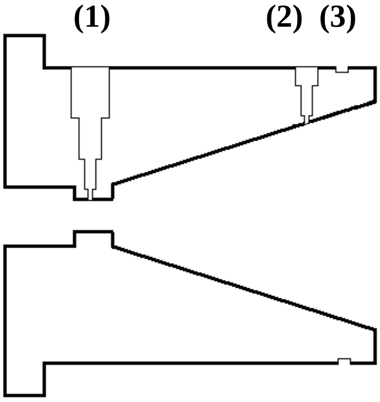

Figure 3 : First conical interface

CFD analysis

The FLUENT® finite-volume package was chosen to solve the Navier-Stokes equations describing the fluid behaviour. The single-phase laws of continuity of mass, momentum and energy, detailed in [5], have been discretized by using the finite volume approach and solved by an iterative Gauss-Seidel method.

The high velocity flow of hot propellant combustion gases can be assumed to be compressible. According to the geometry of the cone, a 2D axisymmetrical formulation for these equations was selected.

Pressure measurements recorded by transducer (1) at the very end of the 20 mm barrel gave us an average value of 12 MPa for the fluid pressure. Doppler in-bore velocity measurements have been used to establish the fluid velocity at about 1300 m/s. These values have been used for the fluid inlet pressure and velocity.

Chemical analysis gave us the fluid composition of the gases : 13.6 % N_2, 13.6 % CO_2, 41 % CO and 31,8 % H_2O. Thermodynamics derived the values of the specific heat capacities Cp = 40.88 J/mol.K and Cv = 27.96 J/mol.K. The value of $\gamma = Cp/Cv$ is equal to 1.47.

The axisymmetrical geometry of the cone allows the use of a 2D solver, significantly reducing computational load because much less cells are required. The fluid zone to mesh comprises the end of the 20 mm gun, the conical interface zone and an expansion zone. Quadrilateral cells are used for zones where the flow is mainly parallel to the x-axis (i.e. the bore axis) and for the expansion zone after the cone. This zone is required in order to minimize the side-effects (backflow for example) and represents an unperturbed zone for the flow. The anticipated area of high flow gradients is more finely meshed by using triangles. Figure 4 shows the strategy of the final mesh of the conical interface and its adjacent zones.

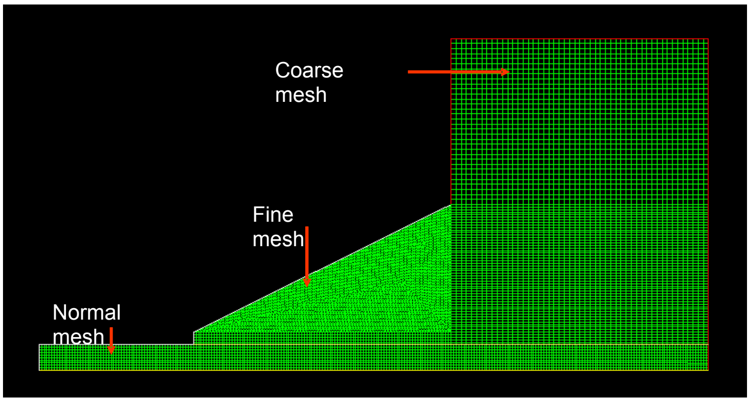

Figure 4 : Meshing strategy

The 2D axisymmetric, double-precision, implicit, unsteady, segregated solver has been used. A standard k-ε model, described in [6], has been chosen for the turbulence set-up. The SIMPLE model was used for the pressure-velocity coupling and the under-relaxation factors were between 0.3 and 0.8. The time step was 10^{-7} s.

Validation and results

A first simulation was made with the original cone. The maximal pressure value recorded from the transducer (2) was compared to the calculated one. We obtained a maximal pressure of 0.47 MPa with Fluent where the measurements gave us 0.41 MPa. This 14% difference was considered as acceptable due to lack of the precision of some of the input parameters.

As solution convergence was reached at each time step, the flow variable contours for the meshed flow field are representative of the flow field for the 3D problem.

The new conical interface angle has been chosen to interfere as little as possible with the fluid expansion. Its value is subsequently equal to the flow expansion angle and is approximately equal to: 12.5 °. Figure 5 shows a photograph of the new conical interface, fitted with two O-rings.

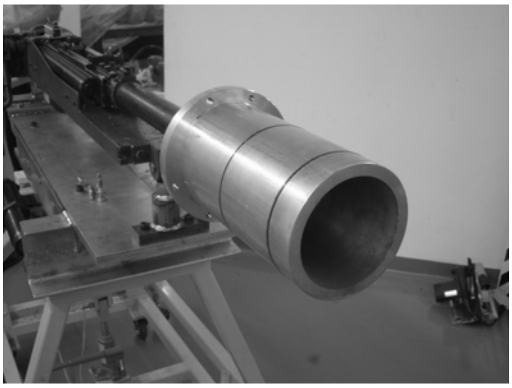

Figure 5 : Photograph of the second conical interface

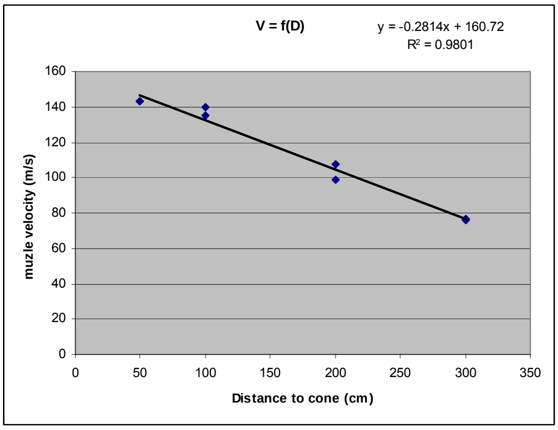

Figure 6 : The velocity/distance curve

SOME TYPICAL RESULTS

Velocities

After having ensured survival of the impactor, different initial positions of the container (in terms of distance to the conical interface) have been used to achieve different velocities. Velocities were measured by high speed video (counting the number of frames and hence the time necessary for the impactor to fly a certain fixed distance) and by a set of two electrical wires put across the barrel, close to the muzzle (tearing the first wire starts a timer, breaking the second stops it). Match between the two measured velocities for a same shot is acceptable as the differences lie between 1 and 11 m/s. For a same initial position, the difference between the mean velocities falls between 0 and 9 m/s.

The graph on figure 6 shows the curve obtained for eight firings, two at each distance. Note that at 50 and 300 cm standoff, the velocities are so close to each other that they appear as a single point on the chart.

Pressures

In order to raise the velocity level to the required 180 m/s, pressure measurements were performed at several spots on the barrels to assess the safety margin of the launcher**.**

It turns out that even when using a case extension to use as much as 40 g of propellant, the pressure values remain comfortably below the maximum permissible values for the barrels.

In-flight picture

The typical high-speed photo in figure 7 shows the gelatine impactor in flight. On the right, the muzzle of the 160mm cannon, on the left the target.

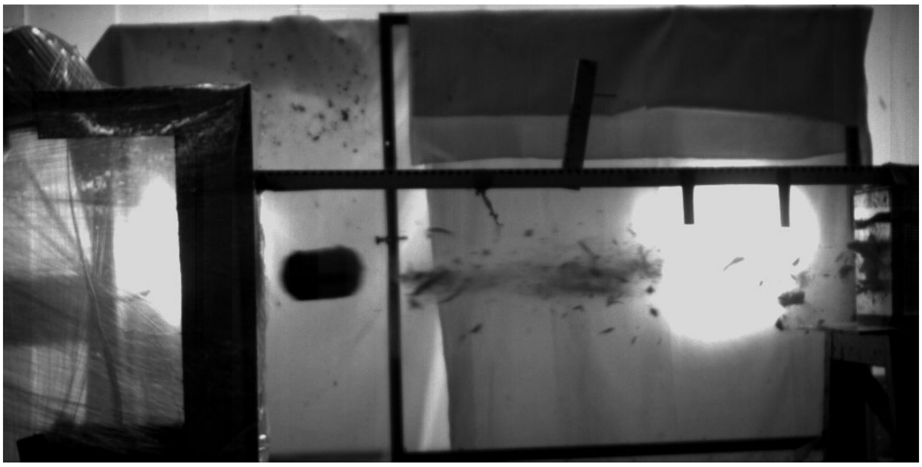

Figure 7 : The projectile in flight

CONCLUSION AND WAY AHEAD

The pyrotechnical launcher developed by the Weapon systems and Ballistics Department of the Royal Military Academy with active participation of SONACA S.A. has demonstrated its capacity to accelerate a 1,8 kg gelatine bird surrogate to velocities up to 150 m/s. The gelatine has been fine-tuned to resist the forces and a linear relation has been identified between the initial position of the container in the barrel (the stand off) and the obtained velocity. The empirical development method is now going to be supported by a parametric mathematical interior ballistics model. The flexibility of the setup and the short response times to implement modifications have already been appreciated by partners from industry.

The next step of this project is to measure the deformation-time curve on the back of the target. A static value of the depth of the sink is certainly interesting, but having dynamic information on how fast the sink is created is much more valuable for the development engineers trying to characterize new types of composite materials. Different metrological approaches are considered, ranging from laser velocimetry to digital image processing.

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