23RD INTERNATIONAL SYMPOSIUM ON BALLISTICS
TARRAGONA, SPAIN 16-20 APRIL 2007

PRELIMINARY DESIGN FOR ISL'S GUIDED SUPERSONIC PROJECTILE

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ISL's project GSP (Guided Supersonic Projectile) is focused on the guidance and control capabilities of air defense ammunitions. This paper presents the preliminary designs of the projectile related to the following fields: aerodynamics, interior ballistics and onboard electronics. The aerodynamic optimization of the projectile was obtained by a CFD parametric approach to investigate the geometry effects on the aerodynamic coefficients. Critical aspects of this study were the fin geometry (lead and trail edge bevel) and the asymmetries created by the open cavities after impulsion. Results were obtained for a Mach number of 3.0 for various angles of attack. A sabot of 40mm caliber was also investigated to ensure the structural integrity during the phase of the in-bore acceleration. To be able to transmit the trajectory data and correction commands from the projectile to a ground station, a special antenna integrated in the tip of the nose projectile and a mechanical transmitter were developed.

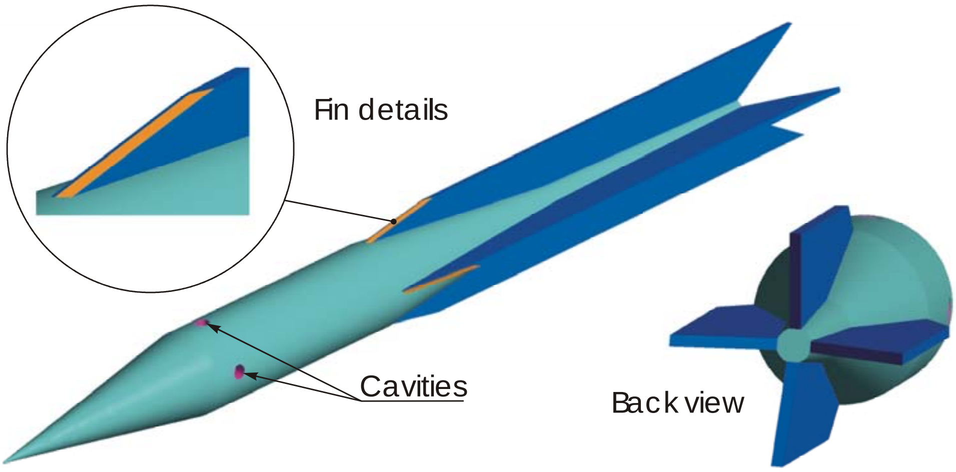
INTRODUCTION

The project GSP (Guided Supersonic Projectile) of the French-German Research Institute is focused on the guidance and control capabilities of air defense ammunitions. From the theoretical results described in [1, 2, 3], this paper presents the preliminary designs of the projectile related to the following fields: aerodynamics, interior ballistics and onboard electronics.

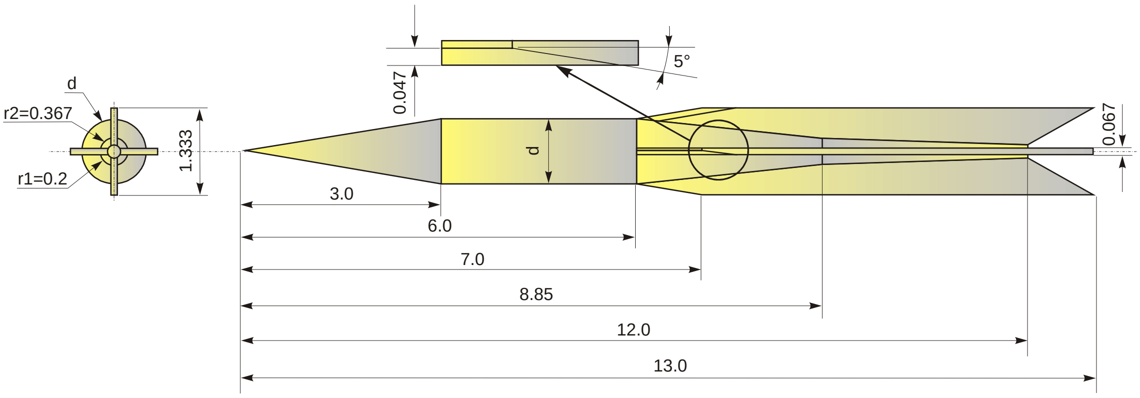
The rationale of the project is to increase the effectiveness of air defense gun systems against maneuvering targets such as attack helicopters, UAVs or cruise missiles. A detailed explanation of this concept is given in [3].

AERODYNAMIC OPTIMIZATION

This study is the continuity of a previous study [1] that has shown the feasibility of using such an ammunition for air defense. The basic aim of this paragraph was to complete the design by taking in account critical aspects such as fin geometry (beveled edge) and the asymmetries created by the cavities left after impulsion. Different configurations were studied starting from a reference model that was modified to progressively end up in an optimized configuration. The reference model was based on



a) View of the optimized projectile



b) Schematic of projectile

Fig.1 – ISL Guided Supersonic Projectile (GSP)

the geometry of a kinetic energy projectile [4] whose fins are not inserted but extracted by machining. The final configuration consists of a conical nose on a cylinder followed by a double boattail with four fins as shown in Fig.1a and 1b. The medium caliber of the projectile is 30mm with a fin span of 40mm and a total length l/d of 13.0. The chord of the fins is equal to 7.0 calibers with a constant thickness of 0.067 calibers. In order to induce a low roll moment leading edges of the fins were beveled asymmetrically. The lead edge cant angle is equal to 5.5° and comparable to the angles used for kinetic energy projectiles. Four impulsers are just located after the nose and have a diameter of 5mm for a depth of 4mm.

Numerical simulations

CFD was essentially carried out to determine the static aerodynamic coefficients that will be used to estimate the flight characteristics of the projectile. Numerical simulation of the flow field were conducted by means of a 3D Navier-Stokes code "CFX11"[*]. Detailed features regarding the numerical simulations are described in reference [5].

Aerodynamic coefficients were obtained by integration of the pressure and viscous forces acting on the projectile. Simulations were conducted for a Mach number of 3.0 and for angles of attack ranging between 0 and 12 degrees. Effects of the bevel angle and the open cavities on the aerodynamic coefficients will be shown, respectively for two angles of 4 and 22 degrees and for four cavities. Overall results show that the beveled leading edges of the fins and the cavities left open after impulsion had negligeable effects on the variation of aerodynamic coefficients as shown in Fig.2a to 2c. They respectively represent for a Mach number of 3.0 and versus angle of attack the variation of the axial force coefficient CA0, the normal force coefficient CN and the pitching moment coefficient Cmα taken towards the base.

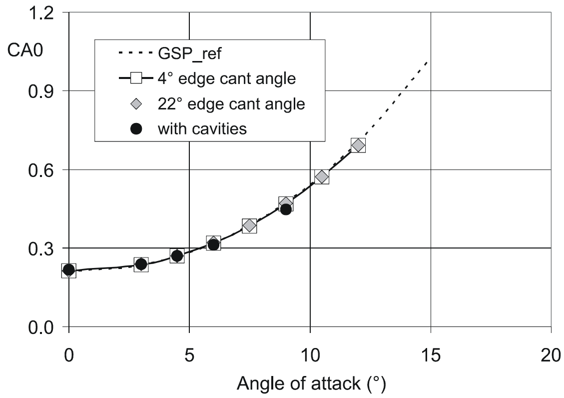


Fig.2a) Axial force coefficient CA0 vs. angle of attack (M=3.0)

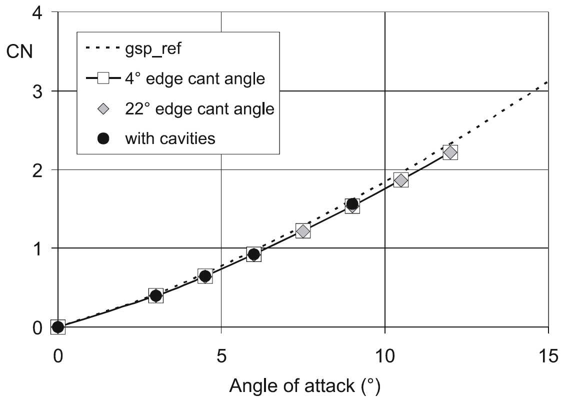


Fig.2b) Normal force coefficient CN vs. angle of attack

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[*] CFX11 ™ is a trademark of ANSYS Ltd.

Figure 3 represents the roll moment coefficient Cl versus angle of attack for a Mach number of 3.0 anf for two lead edge cant angle of 4 and 22 degrees. For a lead edge cant angle of 4 degrees and as expected the roll moment is not equal to zero at zero angle of attack and is increasing up to an incidence of about 7.5 degrees. The same behavior can be observed for a 22° lead edge cant angle with in this case a maximum obtained for an incidence of 10 degrees.

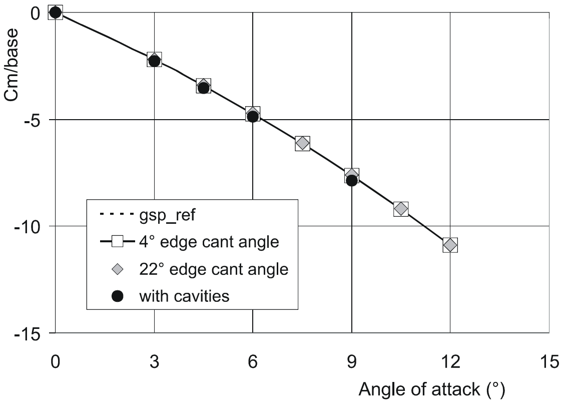

Fig.2c) Pitching moment coefficient Cm/base vs. angle of attack

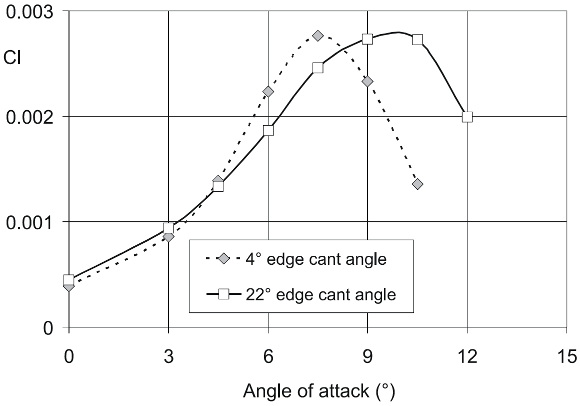

Fig.3 – Roll moment coefficient Cl vs. angle of attack

Free-flight experiments

Before firing the projectile from a 40mm gun, a series of free-flight tests were conducted to validate the results obtained by CFD. For this purpose models were

Fig.4– Photograph of the ISL test set-up

Fig.5 – Model-sabot package

launched at the ISL open range test site from a 105-mm smooth bore gun, as shown in Fig.4. The main objectives of these preliminary trials were to confirm if adequate sabot separation was obtained at the sabot trap and to make sure that the models were stable over a distance of at least 200 m. Doppler radars were used on these trials to obtain the velocity of the projectile as it files down the range. Photograph of the sabot package is shown in Fig.5.

SABOT DESIGN

The GSP shell is to be fired with a 40 mm smooth bore gun, using a cylindrical sabot divided into three or four parts. The sabot is made of high-strength aluminum alloy with a mass of 140 g only. It is fastened to the projectile using a short screw thread. The contact surface betwen the shell and the barrel is provided both by the sabot and the fins, which ensures an excellent stability of the projectile within the tube.

The maximal gas pressure is about 360 MPa in the cartridge case. This pressure is reduced to 280 MPa at the rear part of the projectile due to the co-acceleration of a considerable quantity of the propellant charge shortly after the beginning of the gas expansion. Thus, the resulting acceleration is about 420 000 m/s^2. The constraints within the shell and the sabot have been computed using the NASTRAN code, thanks to the method called "Inertia relief".

Fig.6 shows the von Mises constraints applied to the rear part of the shell. The highest stress level (723 MPa) is located within the metal casing just behind the sabot. This level can be easily sustained by tempered steel such as 42 CrMo 4. Similarly, the stress level within the sabot is sustained by the aluminum alloy. The screw thread also withstands the contact force between the sabot and the shell.

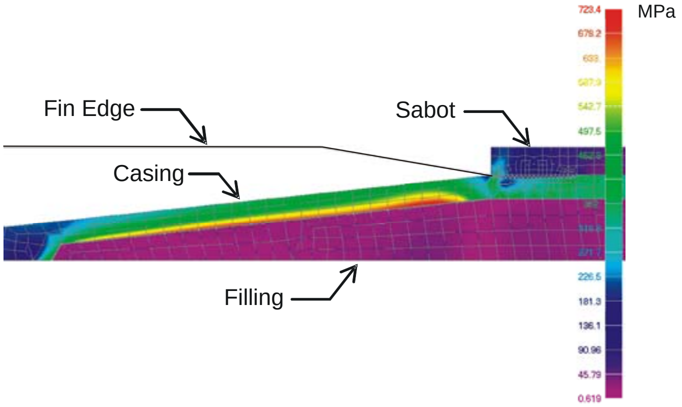

Fig.6 – Von Mises constraints

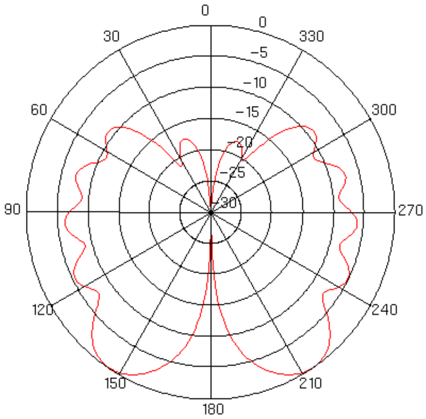

Fig.8 - Cut view of the GSP nose

Fig.9 - Simulated radiation pattern at frequency f=2300 MHz.

A specific antenna has been designed for this projectile, which is located in its nose as shown in Fig.8. It is constituted of a metallic monopole (in grey at the top), a plastic piece (in yellow) and another metallic part screwed in the GPS corps and constituting the ground reference for the antenna. Feeding is obtained with a coaxial cable. Typical radiations patterns are given at Fig.9, indicating that the maximal power is lateral and towards the back, around -145° (nose is pointing toward 0°). The impedance matching of the antenna is obtained with quarter-wavelength transformer by choosing judiciously the lengths and the diameters of the transmission lines in the inferior part of the nose (Fig.2). The measured impedance bandwidth (Return loss <-10 dB) is around 400 MHz and over the whole used frequency band as illustrated by Figure 10.

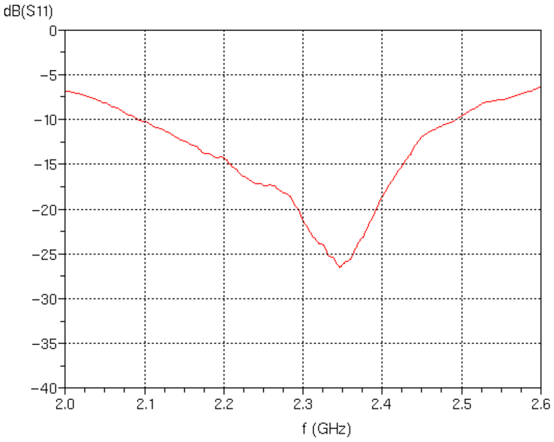

Fig. 10- Measured reurn loss of the antenna mounted on the GPS

Telemetry-Transmitters

Due to the calibre of the GSP- projectile, the mechanical transmitter integration has to be done in a diameter of 20mm and with a height as small as possible. Such a transmitter didn't exist at the ISL so far and had to be developed. For first firing- tests a crystal- stabilized PLL controlled transmitter was developed. This transmitter was designed for a PCM/FM- modulation. The schematic diagram is shown in Fig.11.

We will not give a functional description of the transmitter here, but a detailed description can be found in [6].

Nevertheless we shall mention some advantages of such a transmitter.

- The synthesized radio-frequency is very stable, providing a base for a RF-link with a low BER (bit error rate).
- The synthesized radio-frequency is programmable and thus adaptable for example to the transmitting antenna

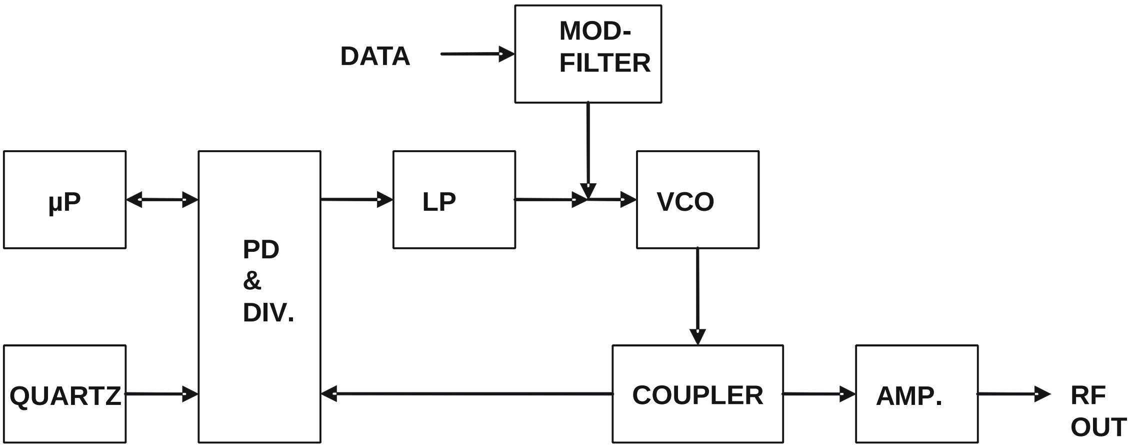

Fig.11 - Schematic diagram of the PCM/FM- transmitter

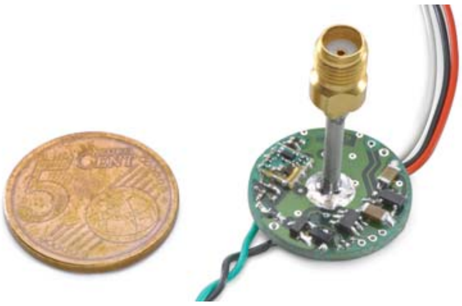

Fig.12 - Photograph
of the PCM/FM-transmitter

After the development was concluded, firing tests were made to verify the shock resistance in ballistic applications. These tests were done at the ISL test range in calibre 40mm. The maximum axial acceleration was approximately 49000g and full functionality could be demonstrated in each shot. A photograph of the PCM/FM- transmitter is shown in Fig.12.

At the ISL test range we also did firing tests with the new transmitters and onboard sensor instrumentation in AFF- projectiles. As in the previous tests the transmitters worked flawlessly and so the quality of the received telemetry stream was very good. Figure 13 shows an example of the received signal strength during these firing tests. Slight drops in the signal strength due to multi path propagation and due to the antenna diagram of the transmitting antenna can be observed. It can easily be seen, that the signal strength is well above the noise floor of the system for the whole duration of the shot.

In a future development phase of the project GSP, the integration of a transceiver in the projectile is planned. Therefore a second type of transmitter was developed, which can be reconfigured as a transceiver later on. First firing tests in calibre 40mm and maximum axial accelerations of approximately 44000g were successfully concluded. A photograph of such a transmitter, using FSK- modulation is shown in Fig.14.

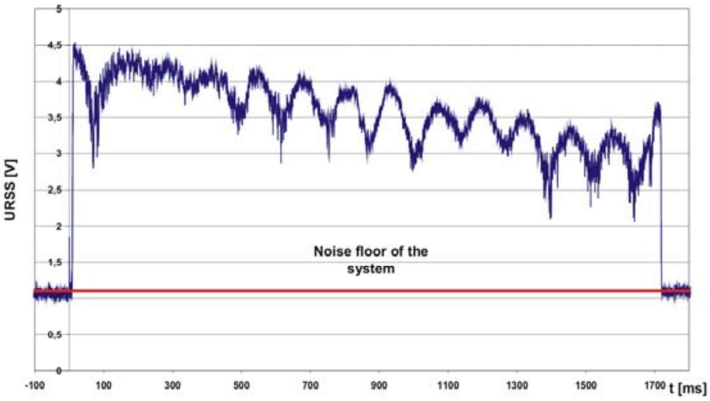

Fig.13 - Received signal strength during shot

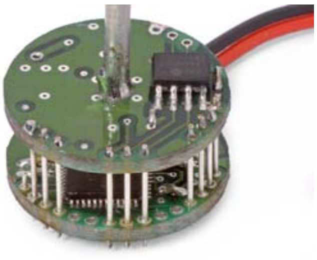

Fig.14 - FSK- transmitter

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