19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

ROLL PRODUCING MOMENT PREDICTION FOR FINNED PROJECTILES

P. Denis[1], P. Champigny[1] and Dr R. Cayzac[2]

[1] Office National d'Études et de Recherches Aérospatiales, 29 Avenue de la Division Leclerc, BP 72, 92322 Chatillon Cedex, France
[2] Giat Industries, Division des Systèmes d'Armes et de Munitions, 7 Route de Guerry, 18023 Bourges Cedex, France

For several years, ONERA and GIAT Industries collaborate on the aeroballistic behaviour of hypervelocity projectiles [1,2]. In order to better estimate the aerodynamics of finned and spinning projectiles, they have decided to support a concerted experimental-numerical action. The attention was focused mainly on the rolling moment with the objective of improving prediction tools. So, wind tunnel tests were carried out, firstly to build up a huge data base, and secondly to improve our knowledge about this problem. Then, a semi-empirical code based on simple theories and on these test results, has been established. Finally, a CFD code was evaluated and many configurations were performed. The tests have clearly shown the influence of the fin design (planform, chamfer angle, sharp or blunt leading edge) on the rolling moment coefficient, and especially the interactions between adjacent fins. Concerning the numerical approach, the results have shown that a global satisfying agreement is obtained. Within a preliminary design, the use of these tools is adequate.

INTRODUCTION

In order to estimate the steady state spin rate of finned projectiles, one needs to know the roll damping coefficient and the fin producing roll moment coefficient. The first term is difficult to obtain experimentally in wind tunnel, because it requires a specific free spinning mechanism. However it can be computed, but in this case high level CFD tools solving unsteady turbulent Navier-Stokes equations are necessary [3]. On the other hand, the prediction of the roll producing moment of canted fins seems to be relatively easier, from either wind tunnel experiments or analytical methods. Nevertheless our studies have shown that, as a matter of fact, it is very difficult to have an accurate prediction of the roll producing moment for classical canted fins (partially canted or chamfered).

So, during this last two years, an experimental program has been carried out in the ONERA wind tunnel, a semi-empirical code has been developed, and a numerical approach has been used to improve the prediction of this coefficient.

Home
Table of Contents

EXPERIMENTAL PROGRAM

Description of wind tunnel tests

The aerodynamic tests were carried out in the ONERA S3MA wind tunnel, respectively at Mach number 2.0, 3.0 and 4.5. This is a subsonic/supersonic blow-down wind tunnel with a variable geometry nozzle. The rectangular test section of the nozzle is 0.80 x 0.76 m.

The main test conditions used at freestream Mach numbers 2.0, 3.0 and 4.5 were: the stagnation pressure values ranges respectively from 1.8 to 6.5 bars and the stagnation temperature between 320 and 350K; then, the Reynolds number lies between 0.62 10^0 and 0.55 10^6 (based on the model diameter of 0.03 m). The angle of attack varies contiauously from –5° to +5°. More than 20 finned projectiles have been tested in two test campaigns. The scale of models is 4/3 and the main geometrical characteristics are: body length values of 16, 25 and 35 calibers, different fins (planform, chamfer angle, sharp or blunt leading edge), different fin arrangements (set of 2, 4 or 6 fins), smooth or threaded body. For the measurements, a specific sting has been designed, and a very accurate roll balance is used. Moreover, the spin of projectiles is given by a tachometer in order to calculate the roll damping coefficient, and flow flied visualisations were also carried out using a Schlieren technique.

Wind tunnel test results

First of all, the Mach number effect has been studied and as an example the results for a 6 fin configuration with chamfered leading edge are plotted on “Fig. 1”. It can be noticed immediately that the rolling moment is not as expected (decreasing with the Mach number), bot completely inverted due to the interaction between adjacent fins.

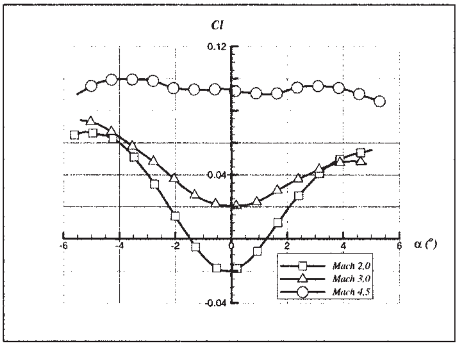

Figure 1: Mach number effect on a 6 fin configuration (L/D=25).

Home
Table of Contents

After that, the influence of the body boundary layer thickness on the rolling moment has been assessed on the same configuration by comparison between different body lengths. The results (“Fig. 2”) clearly show a slight but not negligible influence. In our case, a variation of about 10% of this coefficient is noted. Moreover, it has been observed (“Fig. 3”) that the presence of the thread tends to thicken the turbulent boundary layer, and so to lower the rolling moment, this effect depending on the groove direction.

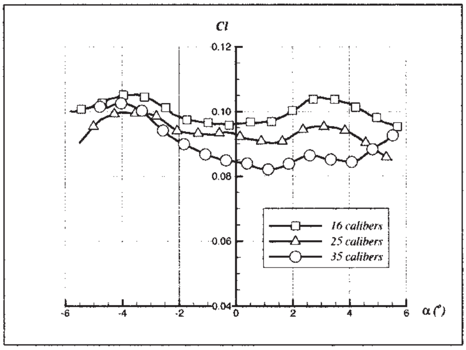

Figure 2: Boundary layer effect (Mach 4.5).

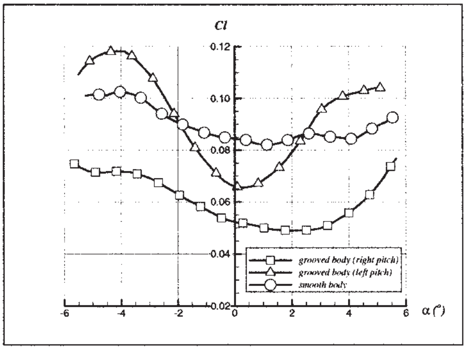

Figure 3: Grooved body effect (Mach 4.5).

Then, the influence of the leading edge sweep angle has been studied at Mach 2.0 and 4.5; the results are respectively presented on “Fig. 4” and “Fig. 5”. It can be observed that for the same fin planform area and chamfer angle, the rolling moment decreases with the sweep angle. A more detailed analysis shows that these results are not only due to the bevelled face but also to the rear flat part of this kind of fin.

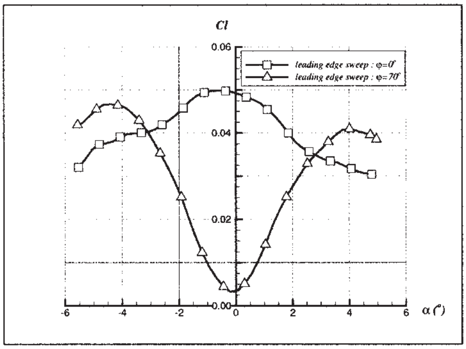

Figure 4: Leading edge sweep effect (Mach 2.0).

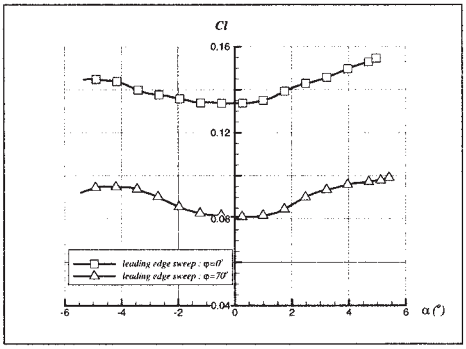

Figure 5: Leading edge sweep effect (Mach 4.5).

Next, a comparison between sharp and blunt leading edge on the rolling moment is presented “Fig. 6” and “Fig. 7”. One can immediately see that the blunt leading edge increases this coefficient for the two Mach numbers. But, as one can see later in the numerical study, this effect is inverted for an isolated fin. Hence, this evolution results once again from the interaction between adjacent fins.

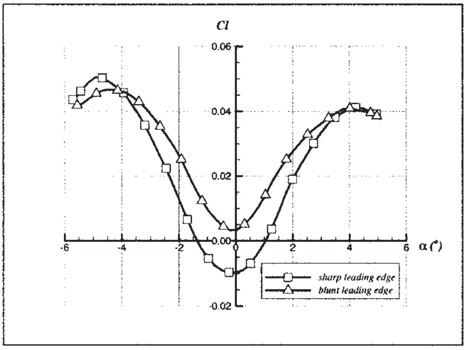

Figure 6: Blunt leading edge effect (Mach 2.0).

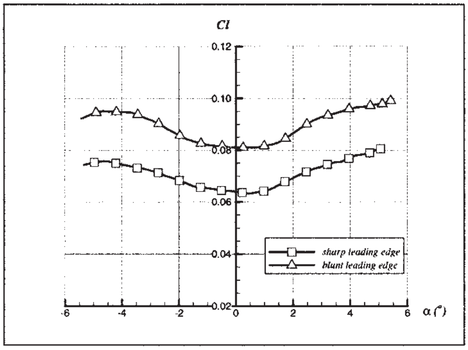

Figure 7: Blunt leading edge effect (Mach 4.5).

Finally, the fin interaction effect is clearly shown on “Fig. 8” and “Fig. 9”, where the results of the configurations with 2, 4 and 6 fins are plotted. For our fin design, we note that the interaction between adjacent fins can reduce the efficiency of the fin section by 50% at Mach 4.5 and leads to invert the spinning direction of the projectile at Mach 2.0. This phenomenon strongly depends on the geometrical characteristics and the number of fins. Among all the described effects, the fin interaction one’s is the most important and must be estimate accurately to obtain a good prediction of the rolling moment.

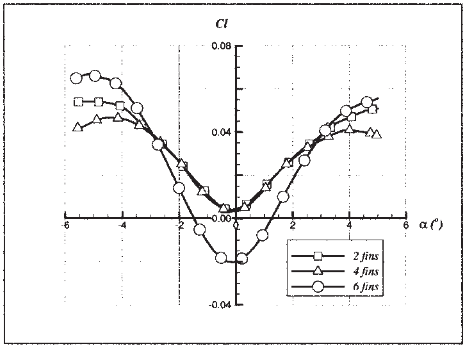

Figure 8: Fin number effect at Mach 2.0 (L/D=25).

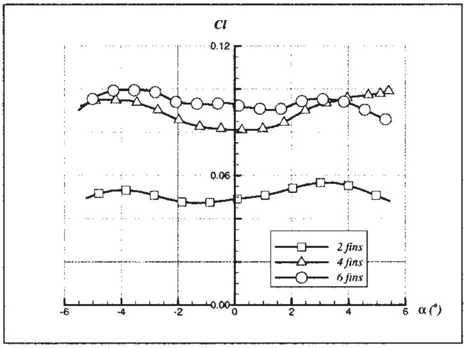

Figure 9: Fin number effect at Mach 4.5 (L/D=25).

NUMERICAL APPROACH

Semi-empirical code

Within the framework of this study, ONERA has decided to develop a semi-empirical code for the prediction of the roll damping and roll producing moment of projectiles. This program, called “ROULIS”, is based on simple theories and test results. Moreover, for the roll producing coefficient, a numerical data base has been made to take into account the fin geometry effect (planform, chamfer angle, sharp or blunt leading edge, ...). More than one hundred configurations were defined. All the computations have been performed on a NEC-SX5 computer, solving the Euler equations with the FLU3M code [4]. The computational time is close to twenty minutes for a mesh of about 730 000 nodes, as presented "Fig. 10". The numerical conditions are: Mach number from 3.0 to 7.0, leading edge sweep angle from 0° to 80°, chamfer angle from 5° to 20° and different levels of leading edge bluntness. From these calculations, the behaviour of each parameters has been analysed and modelled for the semi-empirical code.

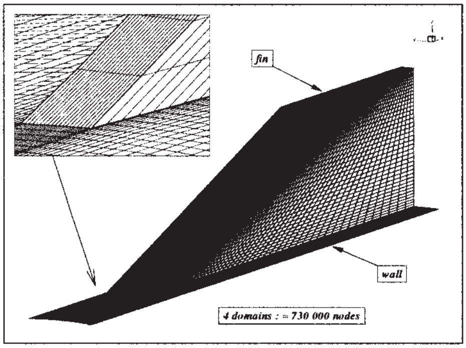

Figure 10: Fin mesh for numerical data base.

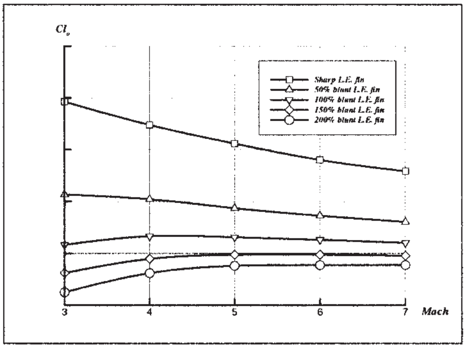

Figure 11: Blunt leading edge effect on isolated fin.

"Fig. 11" shows an example of the numerical results for the blunt leading edge effect. Compared to the sharp one, the bluntness seems to highly decrease the rolling moment of the isolated fin, which is opposed to the experimental results shown previously. As mentioned before, this is due to adjacent fin interaction.

So, to have a good agreement with the test results, these interactions between fins have been calculated for each tested configuration and each flow conditions. Then, a simple corrective factor has been developed, and introduced in the semi-empirical code.

CFD code

A numerical approach has been also used and computations on different fin configurations have been performed on a NEC-SX5 computer, solving the Euler equations with the FLU3M code. For this study, meshes are the same as those used to establish the data base bot now, the fin section is calculated with the body and all the fins are described with a periodic condition in this code.

The result presented hereafter ("Fig. 12") corresponds to a simulation performed at Mach 2.0 on a 6 fin configuration without incidence.

Home
Table of Contents

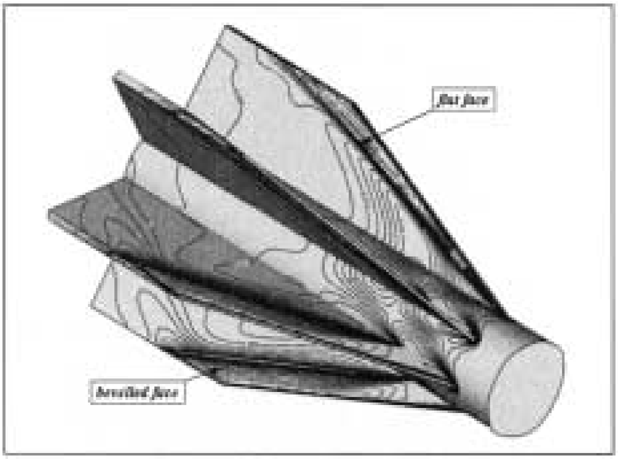

Figure 12: Euler computation on a 6 fin configuration (Mach 2.0/ α=0°).

On this pressure iso-contours representation, one clearly sees the geometry of fins (bevelled and flat faces), the flow compression on the bevelled face and a non-constant pressure on the flat face. On this latter, the shock trace of the adjacent leading edge fin is shown and strongly modifies the pressure distribution. On this example, the interaction is important enough to change the rolling moment sign, and so the projectile spinning.

For the same configuration, other Mach numbers have been studied; the results have shown a good representation of this fin interaction, and consequently a good rolling moment estimation.

A detailed comparison between experimental data, semi-empirical and CFD results is proposod on “Fig. 13”. The chosen case is the 6 fin configuration with a 25 caliber body length, which is representative of a classical projectiles.

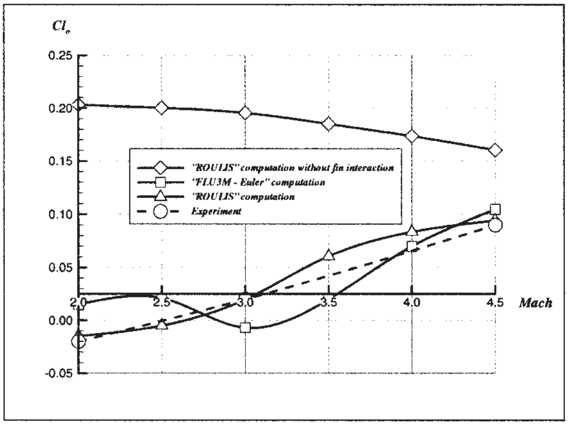

Figure 13: Comparison on a 6 fin configuration (L/D=25).

We clearly see that these tools give an accurate prediction of the rolling moment, and in particular of the trend as a function of the Mach number. Within this preliminary study, these two numerical tools make a good mean for the prediction of the rolling moment of finned projectile.

CONCLUSION

To predict the rolling moment of finned projectiles, ONERA and GIAT-Industries have worked in three directions. The first one is experimental, with an important test campaign which has given a huge data base relative to the rolling moment projectiles. The second one concerns the development of a semi-empirical code called “ROULIS”, and the last aspect is the assessment of a CFD code. At present time, Euler computations coupled with semi-empirical give a correct estimation for a preliminary study. Nevertheless, improvements are necessary, in order to better take into account all the parameters. This will be done in the future within the framework of a program funded by the French MOD, where new experiments will be done, as well as Navier-Stokes computations.

REFERENCES

1. Dr. Cayzac R., Champigny P., and Warken D., “Kinetic Projectiles for Electric Guns: Aeroballistics Investigations”, 16th International Symposium on Ballistics, San Francisco, CA, Sept. 1996.
2. Denis P, Champigny P., and Dr Cayzac R., “Kinetic Projetiles for Electric Guns: Experiments computations”, 18th International Symposium on Ballistics, San Antonio, TX, Nov. 1999.
3. Dr. Cayzac R., Péchier M., and Guillen Ph., "Navier-Stokes Computations and Validations of yawing and spinning projectiles", 18th International Symposium on Ballistics, San Antonio, TX, Nov. 1999.
4. Cambier L., Darracq D., Gazaix M., and Guillen Ph., “Améliorations récentes du code de calcul d'écoulements compressibles FLU3M”, AGARD Séville, Spain, Oct. 1995

Home

Table of Contents