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

RANS/LES SIMULATIONS OF PROJECTILES WITH AND WITHOUT ROTATION IN THE SUBSONIC AND TRANSONIC REGIMES

F. Simon[1], S. Deck[1], P. Guillen[1], R. Cayzac[2] , P. Sagaut[3] and A. Merlen[4]

1 *ONERA, BP72 – 29 avenue de la Division Leclerc, FR-92322 Chatillon Cedex, France*
Phone: +34 913 366 683, Fax: +34 913 366 680, email: sebastien.deck@onera.fr

2 *Giat Industries, Département Balistique Intérieure et Aérobalistique, 7 route de Guerry, 18023*
Bourges Cedex, France, email: r.cayzac@giat-industries.fr

3 *LML, UPMC/CNRS, Boite 162, 4 place Jussieu, 75252 Paris Cedex 05, France*

4 *Université des Sciences et Technologies de Lille (Lille1), Laboratoire de Mécanique de Lille,*
Cité scientifique - Bâtiment M3 , 59655 Villeneuve d'Ascq Cédex, France

The recent advances in turbulence modelling methodologies [1] allow for taking into account the unsteady dynamics of projectile flows at high Reynolds number. Such numerical procedures are required for improving flow prediction in the subsonic and transonic regimes [2]. Several simulations of the flow around a secant ogive cylinder boattail configuration (SOCBT) have been achieved and compared to available experimental data [3][4][5]. A zonal detached-eddy simulation methodology [6][7] has thus been used to perform unsteady simulations. Both time-averaged and unsteady results are provided to get a better insight into the physics of such flows. The influence of the Mach number and of the rotation is assessed for both static averaged coefficients and fluctuations.

INTRODUCTION

In order to evaluate the influence of Mach number and rotation for spinning projectiles, an hybrid RANS/LES approach called ZDES is proposed to numerically simulate the subsonic and transonic flow over a SOCBT configuration. This method allows to take into account the unsteadiness of the flow in the base region. After a brief presentation of the numerical method and turbulence modelling, we concentrate on the validation for non spinning cases. The influence of rotation is then estimated numerically.

SOLVER

The multiblock Navier-Stokes solver used in the present study is the FLU3M code developped by ONERA. The equations are discretized using a second-order accurate upwind finite volume scheme and a cell-centered discretization. The Euler fluxes are discretized by a classical Roe scheme with an Harten coefficient of .01 and a limier of Koren. Time discretization is based on second-order Gear's formulation as presented by Péchier [8]. Further details concerning the numerical procedure can be found in [9]. This numerical strategy has already been applied with success to a wide range of turbulent flows [10].

TURBULENCE MODELLING

The turbulence modelling used here is the ZDES technique proposed by Deck [6][7] and decribed in details in these last references. Basically the Detached eddy simulation was proposed by Spalart et al [11], and has given encouraging results for a wide range of flow configurations exhibiting massive separation, see [12] for instance. The motivation for this approach was to combine the best features of a RANS approach with the best features of LES. The main concern in this technique is the switch between this two modes. In the original method it was done by replacing a reference length, the distance to the closest wall by the min of this distance and a calibrated length based on the computational mesh size. If this switching occurs inside the RANS boundary layer, it results in an underestimation of the skin friction coefficient. To avoid this problem in the attached boundary layer, the ZDES approach, for Zonal Detached Eddy Simulation, where attached boundary layers are explicitly treated in RANS mode regardless of the grid resolution, has been proposed.

TEST-CASES

The geometry of the projectile is presented on Figure 1. If D is the diameter of the cylindrical part, the total length is of 6D., the ogive one of 3D. The projectile ends with a boattail of 7 degrees on a 1D length.

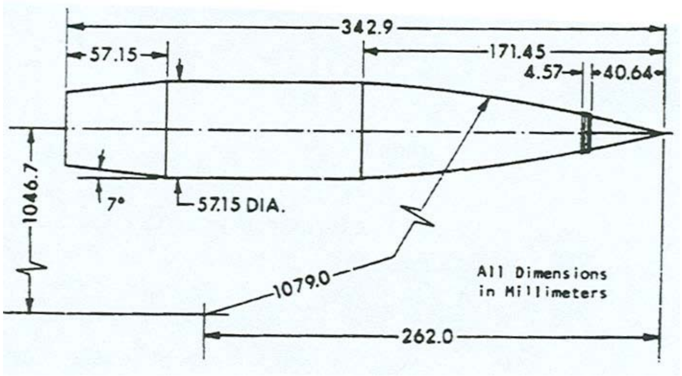


Figure 1. Geometry of the SOCBT configuration

The freestream Mach numbers have been chosen to fit with the experimental data available. Due to the important required CPU time, about a few hundreds of CPU hours on a NEC SX-8, 4 computations only have been achieved all at zero degree of incidence for the following Mach numbers : .5, .7, .91, 1.05. Total Pressure is equal to 100 kPa and total temperature to 320 K what leads to Reynolds numbers based on the length of the projectile and the freestream speed going from 3.3 to 4.4 millions.

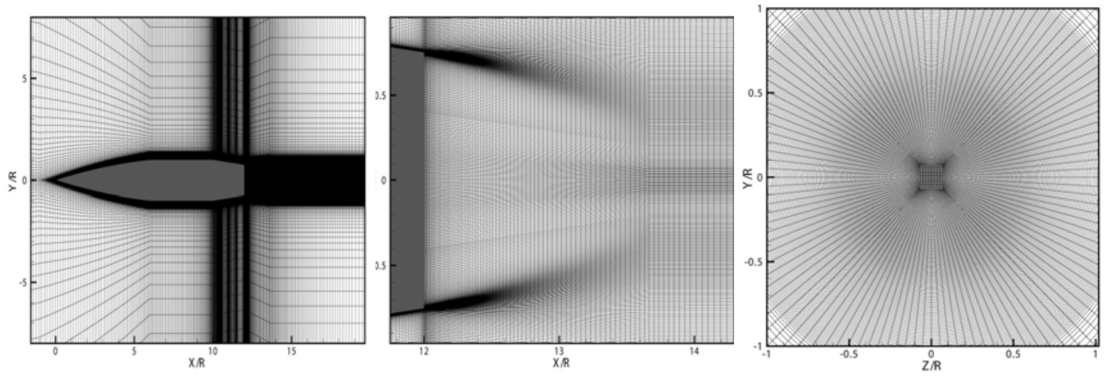
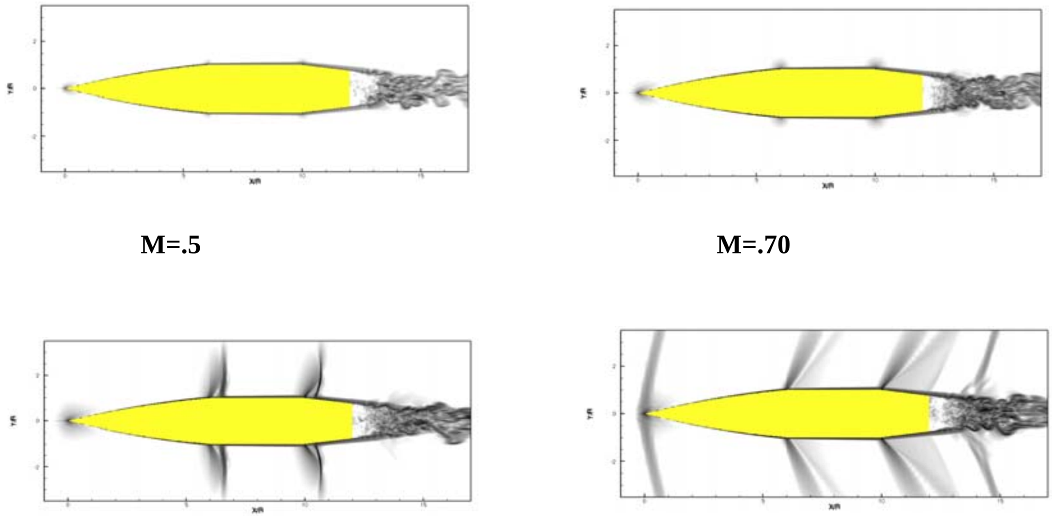


Figure 2. mesh views

Different views of the mesh are presented on Figure 2. The 3D mesh has been generated with the MESH3D code [13] and contains 7 587 000 cells distributed on 17 blocks. The frontiers of the computational domain are situated at 20D in front of the projectile, and 30D behind and on the sides. The turbulent Boundary Layer on the body is discretized with 45 nodes in the outward radial direction. The ratio of the boundary layer thickness to the radius is of 17% at the end of the boattail.

RESULTS ON NON SPINNING CONFIGURATIONS



M=.5 **M=.70**

M=.91 M=1.05

Figure 3. Numerical Schlieren numerical visualizations

Figure 3 presents instantaneous numerical Schlieren visualizations for the the 4 freestream Mach numbers. As expected for the subsonic configurations gradients are visible at the nose and at the discontinuities of the body slopes. For the Mach .91 case the expansions and shockwaves are clearly visible. A closer look at the computation shows that the shockwaves are not stationary, they do oscillate with a Strouhal number based on D and the freestream speed of .03. For the supersonic case a shock is created in the wake region. For all test cases the unsteadiness in the base region is clear.

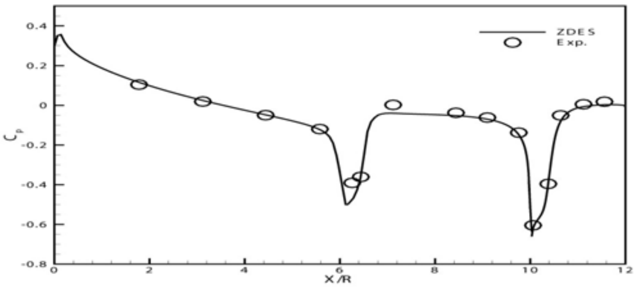
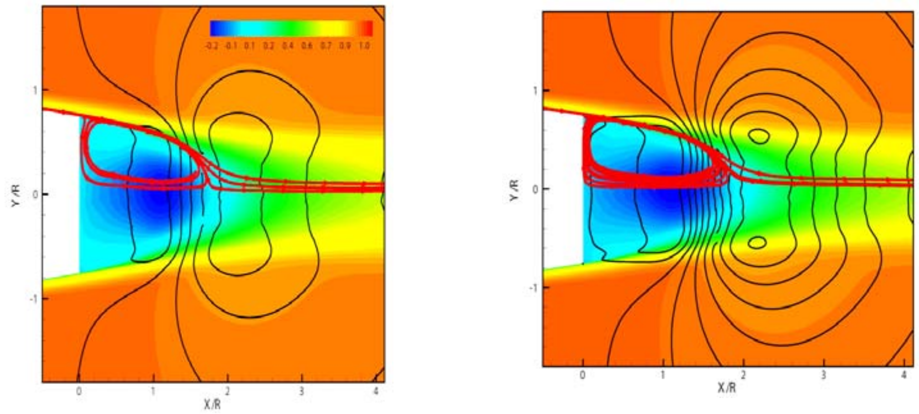


Figure 4. Wall pressure coefficients

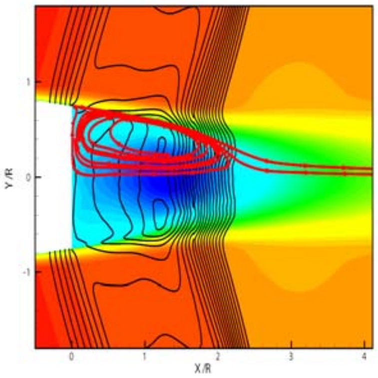
Figure 4 presents a comparison between computed and experimental mean pressures on the surface along the axis for the .91 Mach number. As one can see the agreement is quite correct.

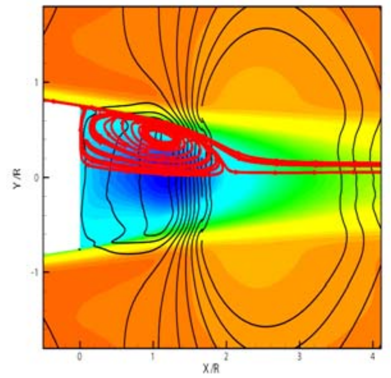
BASE FLOW



M=.50

M=.70





M=.91 M=1.05

Figure 5. Base flow topologies

We now concentrate on the averaged characteristics of the base flow. Figure 5 shows the mean Mach numbers, pressure contours and streamlines in the base region for the different freestream Mach numbers. The flow topology with a separated area seems very close for all the test cases. As expected, the length of the separated area increases with the Mach number.

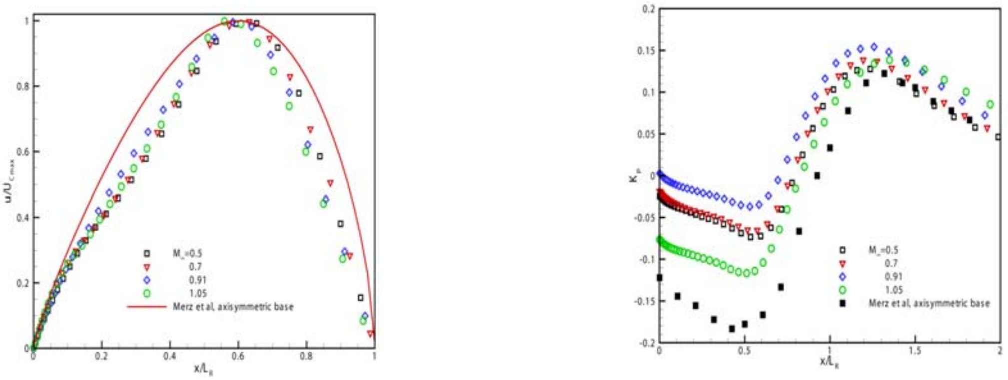


Figure 6. Axial speed and pressure coefficients along the axis in the separated area

The evolutions of the pressure coefficient along the axis in the base region are plotted in the right part of Figure 6 where the x coordinate has been dimensioned by the length of the separated region. The data is compared with the one of Merz [14], that was obtained for a base flow without boattail. In the first part of the separated region the pressure levels increase with the Mach number and are quite different from those obtained by Merz. They all converges to similar values after the recompression. In the left part of the figure the longitudinal speed dimensioned by its maximum replaces the pressure for the y coordinate, the abscissa remaining unchanged. One can notice the similar behaviour for all simulations.

To identify the level of resolution of the simulation and to evidence the coherent structures in such flows, the Q-criterion [15] has been used. Figure 7 presents this criterion for the 1.05 Mach number test-case. One can notice the development of some bidimensional structures issued from the Kelvin-Helmholtz instabilityin the wake just after the separation.

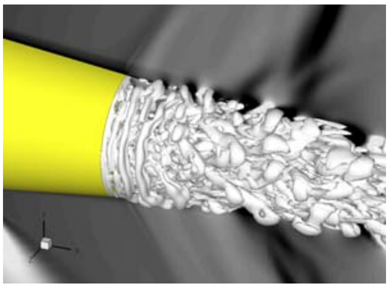
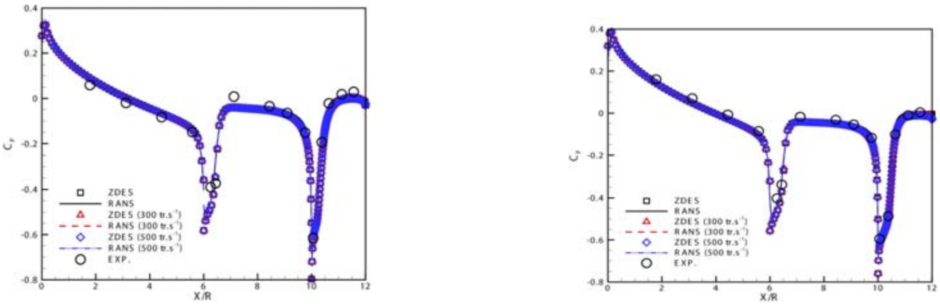


Figure 7. Q contours

ROTATION INFLUENCE

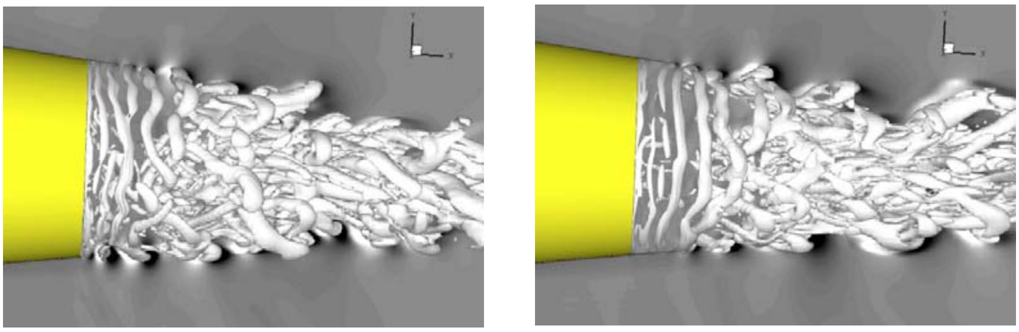
In order to appreciate the effects due to the rotation, a test-case at Mach number .91 and 2 degrees of incidences has been computed for three values of Ω : 0., 300 rps, 500 rps. Figure 10 compares the pressures along the body respectively at the windside and leeside. As can be seen no significant differences has been found.



Leeside Windside

Figure 10. Schlieren numerical visualizations, influence of rotation

Concerning the unsteady aspects, a similar conclusion can be drawn, this can be seen for instance for the Q criterion on Figure 12.



Non spinning **Spinning**

Figure 12. Q contours, influence of rotation

CONCLUSION

Hybrid RANS/LES of the ZDES type proposed by S. Deck have been performed on a SOCBT configuration. Good comparisons with experimental data has been obtained on non spinning configurations. Numerical simulations of spinning cases do not exhibit significant differences for steady or unsteady characteristics.

REFERENCES

1. P. Sagaut, S. Deck, M. Terracol, Multiscale and multiresolution approaches in turbulence, *Imperial College Press* (2006)
2. R. Cayzac, E. Carette, P. Champigny, R. Thépot, O. Donneaud, Analysis of static and dynamic stability of spinning projectiles, 21st International Symposium on Ballistics, Adelaide, South Australia, 19-23 April, 2004
3. L. D. Kayser, F. Whiton, Surface pressure measurements on a boattailled projectile shape at transonic speeds, *Ballistic Research Laboratory*, *Memorandum Report ARBRL-MR-03161* (1982)
4. C. J. Nietubicz, W. B. Sturek, K. R. Heavey, Computations of projectile Magnus effect at transonic velocities, *AIAA J.*, **23 (7)**, 968-1004 (1983)
5. M. C. Miller, Surface pressure measurements on a transonic spinning projectile, *J. Spacecraft*, **22 (2)**, 112-118 (1984)
6. S. Deck, Numerical simulation of transonic buffet over a supercritical airfoil, *AIAA J.,* **43 (7)** (2005)
7. S. Deck, Zonal-detached eddy simulation of the flow around a high lift configuration, *AIAA J.,* 43 (11), 2372-2384 (2005)

8. M. Péchier, Ph. Guillen, R. Cayzac, Magnus Effects over Finned Projectiles, Journal of Spacecraft and Rockets, Vol. 38, Nº4, 2001, pp 542-549.
9. F. Simon, S. Deck, P. Guillen, P. Sagaut, Reynolds-Averaged Navier-Stokes Equations/Large Eddy Simulations of Supersonic Base Flow, AIAA Journal, Vol.44, No 11, (2006)
10. S. Deck, P. Duveau, P. D'Espiney, and P. Guillen,Development and Application of Spalart-Allmaras One Equation Turbulence Model to Three-Dimensional Supersonic Complex Configurations, Aerospace Science and Technology, Vol. 6, No 3,pp.171-183, (2002)
11. P.R. Spalart, W. H. Jou, M. Strelets,and S.R. Allmaras, Comments on the Feasibility of LES for Wings and on a Hybrid RANS/LES Approach,Proceedings of the First AFSOR International Conference on DNS/LES.
12. S. Deck, E. Garnier, and P. Guillen, Turbulence Modelling applied to Space Launcher Configurations, Journal of Turbulence,Vol. 3, No 57, pp1-21,(2002)
13. F. Montigny-Rannou, O.P. Jacquotte,MESH3D un outil pour la construction de maillages tridimesionnels,AAAF 29ème colloque d'aérodynamique appliquée, CEL Biscarosse, (1992)
14. R. A. Merz, R. H. Page, C. E. G. Przirembel, Subsonic axisymmetric near-wake studies, *AIAA J.*, **16 (7)**, 656-662 (1978)
15. J. Jeong, F. Hussain, On the identification of a vortex, *J. Fluid Mechanics*, **285**, 69-94 (1995)