AERODYNAMIC CHARACTERISTICS OF A RECOVERABLE ORBITAL PLATFORM AT HIGH SPEED FLOWS

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Abstract

The main aerodynamic parameters involved in the design of a capsule returning from space are force coefficients, moment coefficients, and their variation with Mach number and angle of attack. The aim of the present study is to evaluate these parameters for the configuration of the Recoverable Orbital Platform SARA under development at IAE-CTA, with better accuracy than possible with the use of engineering methods. The three-dimensional, viscous governing equations are solved numerically by employing a LU-SGS algorithm based on a finite volume discretization. Results are obtained for angles of attack ranging from zero to 10 degrees, and Mach numbers ranging from 2 to 6. The results from the numerical computations are compared with calculations applying engineering methods for verification purposes. Validation is further obtained by comparing the bow shock wave detachment position, and shock shape numerically computed with the results of calculations using semi-empirical formulas.

Keywords: aerodynamic coefficients; supersonic flow; orbital platform.

1. INTRODUCTION

Knowledge of the aerodynamic behavior of a capsule returning from space is of paramount importance to determine its trajectory and to establish its stability characteristics. The main parameters involved are force coefficients, moment coefficients, and their variation with Mach number and angle of attack. In the beginning of a design process, engineering methods are used to approximate these parameters. However, as design evolves, more accurate evaluations of these parameters are necessary. Hence more sophisticated methodologies must be used for this purpose. The usual methods employed to refine the accuracy of the aerodynamic parameters comprise numerical simulations and wind tunnel tests. The former involves the solution of the complete set of governing equations in 3-D formulation for the whole range of Mach numbers and angles of attack. The latter is then employed for verification and further refinement.

The aim of the present study is to evaluate the aerodynamic parameters for the configuration of the Recoverable Orbital Platform SARA under development at IAE-CTA (Moraes,1998), with better accuracy than possible with the use of engineering methods. The three-dimensional, viscous governing equations are solved numerically by employing a LU-SGS algorithm based on a finite volume discretization. To perform the numerical computations a plane of symmetry, corresponding to the plane of varying angle of attack, is employed. Hence only half domain is discretized. Results are obtained for angles of attack ranging from zero to 10 degrees, and Mach numbers ranging from 2 to 6. The results from the numerical computations are compared with calculations applying engineering methods for verification purposes. Validation is further obtained by comparing the bow shock wave detachment position, and shock shape numerically computed with the results of calculations using semi-empirical formulas.

2. PROBLEM DEFINITION AND SOLUTION APPROACH

2.1 Body Geometry

The geometry of the configuration used in the present study is shown in Fig. 1.

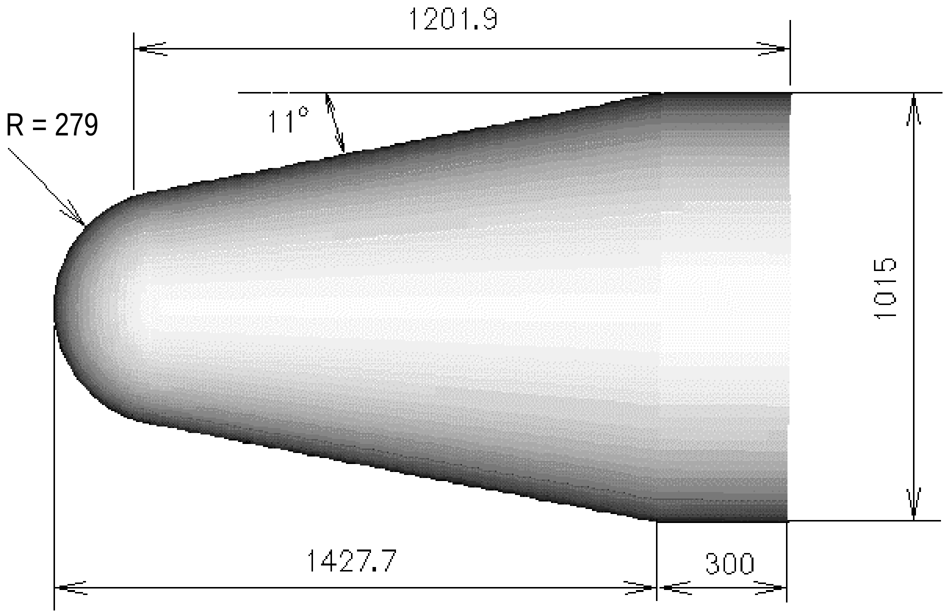

Figure 1. Geometry of the configuration. Dimensions in mm.

The capsule is a blunt hemisphere-cone-cylinder with dimensions given in mm, with an 11° cone half angle.

2.2 Flow Conditions

Freestream Mach number ranged from 1.55 up to 6.63, Reynolds number per meter 2.48 x 10^6, and angles of attack varying from 0° to 10°. The flow conditions were selected to represent the reentry trajectory of the capsule from the lower hypersonic regime to the supersonic regime.

2.3 Engineering Calculations

To perform the engineering calculations, two different methodologies have been applied which are based on analytical formulations enhanced by empirical data calibration.

The determination of the stability derivatives, normal force and pitch moment coefficients, and later the longitudinal position of the center of pressure, makes essentially use of experimental data in form of load distributions along the individual components. These component-wise computations are then combined and integrated to the give the complete configuration results (Faggiano *et al*., 1985).

Drag coefficients are calculated using a procedure based on analytical formulations for the several drag components, corrected with wind tunnel data, specially with respect to the base drag contribution. The Reynolds number influence is also taken into account with the use of Standard atmosphere data (Delprat, 1992).

2.4 Computational Grid

The three-dimensional computational grid employed in this study is presented in Figure 2. A two-block grid was used where the number of grid points in the axial, circumferencial, and radial, directions are 17x22x53 and 60x52x53, respectively. The grid was constructed exploiting the symmetry characteristics of the fowfield in the x-z plane. Hence, only half plane of the physical domain was discretized.

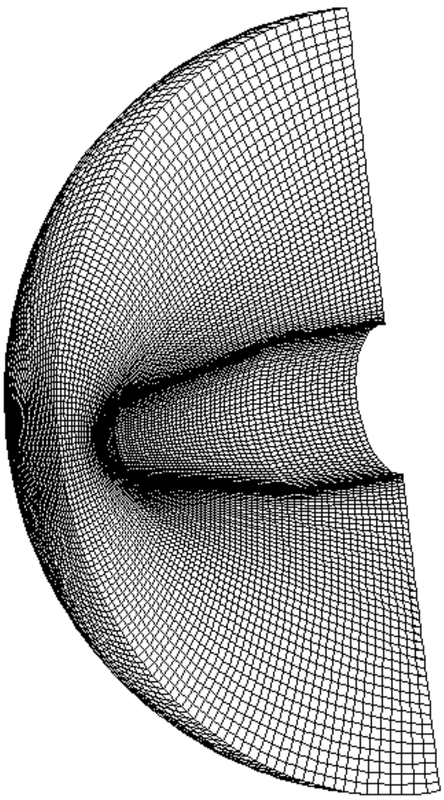

Figure 2. Computational grid, 17x22x53 and 60x52x53 grid points

2.5 Numerical Algorithm

The compressible laminar flow under consideration over a capsule returning from the upper atmosphere is governed by the Navier-Stokes equations, which are written in strong conservation law form in a generalized coordinate system. The equations are solved using the lower-upper symmetric-Gauss-Seidel factorization scheme proposed by Yoon, S. and Kwak, D. (1992). The advantage of this factorization scheme is that the construction of the diagonal of the L and U matrices permits a scalar inversion, leading to a very efficient and vectorizable algorithm.

2.6 Initial and Boundary Conditions

The initial flowfield is set to be freestream everywhere. All variables are extrapolated at the outflow boundary and nonslip wall condition is applied on the surface of the body. Adiabatic wall condition is imposed at the wall.

3. RESULTS AND DISCUSSION

The axisymmetric flow at zero angle of attack was computed and the principal flow features were compared with results calculated by empirical formulas given by Anderson (1989). Figure 3 shows the comparison of the computed shock shape with that given by the empirical formula. The comparison between the numerical results and the empirical formula show good agreement. Figure 4 shows the pressure distribution along the stagnation line for Mach numbers 2.55 and 5.42. Also shown in Fig. 4 as vertical lines, the position of the standoff distances computed by the empirical formulas for the two Mach numbers considered. The agreement between the numerical and empirical formulas results is good. Nevertheless, the shock for the lower Mach number presents a less steep pressure jump when compared with the higher Mach number case. This is attributed to the spacing of the grid distribution in that region, since the standoff distance for the lower Mach number is further away from the body

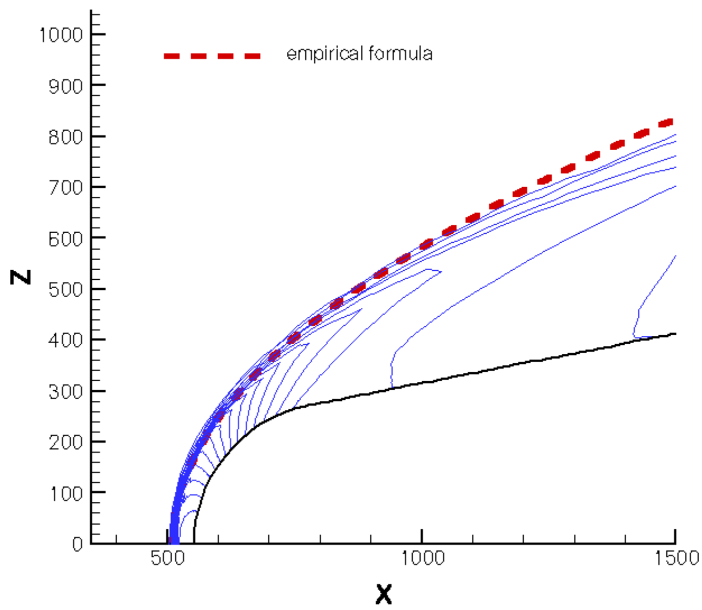

Figure 3. Computed pressure contours vs. shock shape correlation. M=6.63.

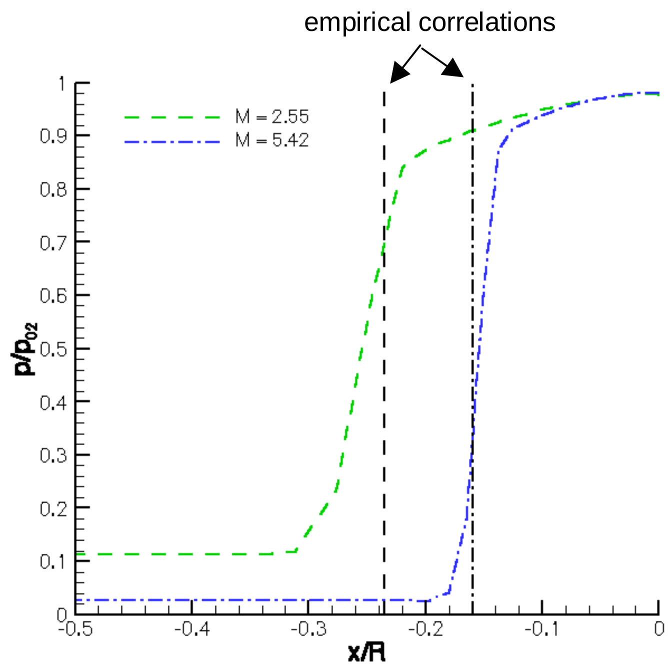

Figure 4. Shock standoff distance comparison.

nose, and the computational grid gets coarser with increasing distance from the body.

The drag coefficient Cd is presented in Fig. 5. The numerical computations include both pressure and viscous contributions. However, the contribution from the base region is not included, i.e., the pressure in the base region is assumed to have the freestream value when computing the drag coefficient. The agreement between the results can be considered good due to the fact that the computational model did not consider the flow in the base region of the vehicle.

The derivative of the normal force coefficient C_N with respect to angle of attach α, $C_N\alpha$,

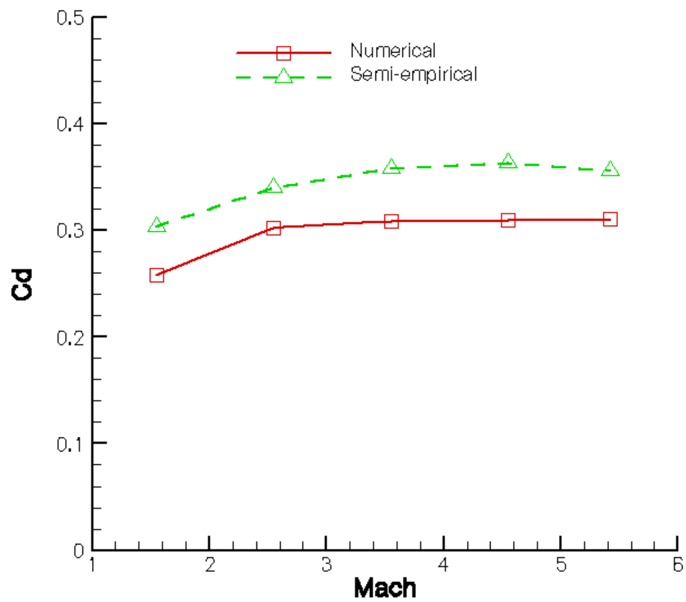

Figure 5. Drag coeficiente, $\alpha = 0°$.

is shown in Fig. 6 as a function of the Mach number. While the results obtained with the semi-empirical calculation method show an almost constant behavior, the results coming from the numerical simulation presents larger decreasing values for the low supersonic regime. This is probably due to the capture of transonic features of the flow. For higher Mach numbers the

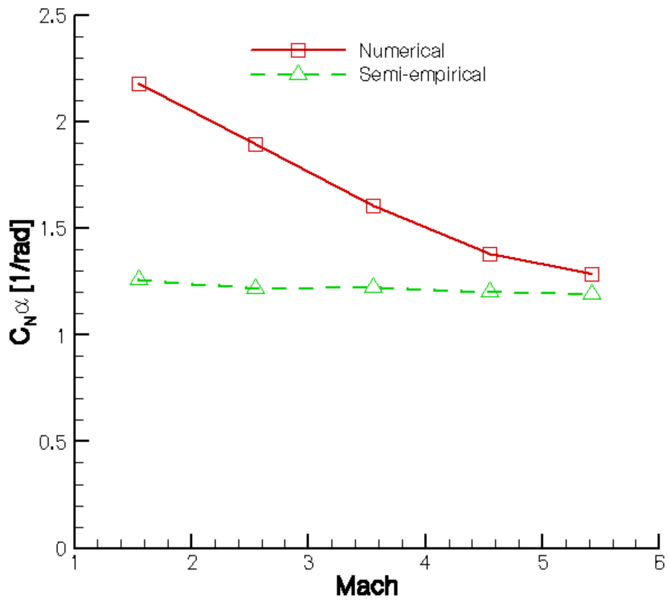

Figure 6. Cnα vs. Mach number.

differences practically disappear between both results and converge to an agreement.

The longitudinal position of the center of pressure Xcp, related to the total length of the vehicle Lref, and plotted as function of the Mach number, is shown in Fig. 7. Both results show similar behavior while the differences are still large. The center of pressure is

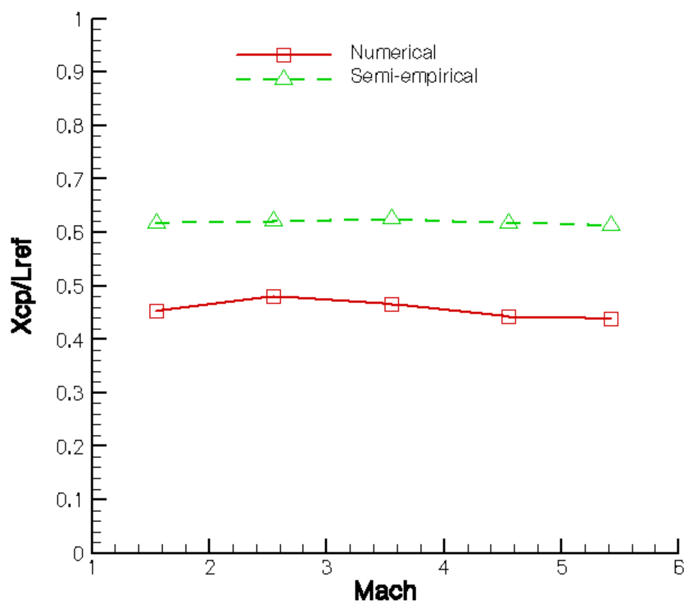

Figure 7. Longitudinal position of the center of pressure, Xcp, vs. Mach number.

determined by the ratio of the derivatives of pitching moment to normal force coefficients. The differences are probably due to the non-agreement of $C_N\alpha$ shown in the previous Fig. 6.

4. CONCLUSIONS

The main aerodynamic parameters, force coefficients, moment coefficients, and their variation with Mach number and angle of attack, for the configuration of the Recoverable Orbital Platform SARA were calculated numerically and with the use of engineering methods. The main features of the flow field compared very well with those obtained by empirical formulas. The comparison of integral results for forces and their variation with angle of attack showed the same curve trends in both methodologies employed. Although the numerical values obtained presented some large discrepancies, those differences are attributed to the lack of accounting for the base flow in the numerical computations. Nevertheless, further investigation is necessary to validate the numerical results, comparing them with experimental data.

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