Application of Modified Newton Flow Model to Earth Reentry Capsules

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Abstract: *This paper presents an implementation of the modified Newton method for the aerodynamic analysis of Planetary Reentry Capsules. A straightforward method is employed, such that a CATIA model and its hybrid surface mesh are used as input. Reference capsules are analyzed and results are compared to other similar codes. Future improvements of the code consider the Busemann correction of the wall pressure, heat flux evaluation and unsteadiness in order to enable the analysis of the hypersonic portion of trajectory and to assess the vehicle's stability.*

Key Words: *Planetary Reentry Capsule, Modified Newton model, aerodynamic analysis, trajectory analysis.*

1. INTRODUCTION

The reentry capsules have been developed since there is a continuous expansion of the mankind towards the extreme frontiers of the Universe, and hence, this increased the demand for appropriate technical equipment and device.

Reentry capsule configurations significantly differ from each other due to entry conditions, trajectory, and a number of aerodynamic factors such as aerodynamic axial force, normal force, static moment, damping coefficients.

The flow-field over the reentry capsule becomes further complicated due to the presence of corner at the shoulder and the base shell of the reentry module.

A high-speed flow-past a reentry capsule generates a bow shock wave which causes a rather high surface pressure and as a result the development of high aerodynamic drag which is required for aero-braking purposes.

Highly blunt configurations are generally preferred to decelerate the space-capsule for safe returning on the Earth after performing the experiments.

The bow shock wave is detached from the blunt fore-body and has a mixed subsonic supersonic region between them.

The wall pressure distribution, the location of the sonic line and shock stand-off distance on the spherical cap region have been analytically calculated at very high speeds with an adiabatic index near to unity which gives a singular point at 60 deg from the stagnation point (Chester 1956; Freeman 1956), Van Dyke [16].

The analytical approach for the high-speed flow over the blunt-body is considerably difficult and complex (Lighthill 1957), [17].

The work confirms that high-temperature transport phenomena markedly influence the vehicle flowfield and, in turn, the vehicle aerodynamics and aerothermodynamics, but it also stresses that, with an acceptable loss of results accuracy, there is not necessary to use models of such high complexity, and therefore considerable computing time can be saved.

Safe landing of vehicles re-entering from space requires an accurate understanding of all physical phenomena that take place in the flowfield past the hypersonic vehicle to assess its aerodynamics and aerothermodynamics performance.

Real gas effects have strongly influence on both aerodynamics and aero-thermal loads of hypervelocity vehicles, as shown by flight measurements collected during reentry. The trajectory calculation for atmospheric reentry involves determining the vehicle aerodynamics and aerothermodynamics.

As a consequence, the accurate modeling of flow physics, in particular the flow chemistry is fundamental to reliably design reentry vehicles.

On the other hand, high accuracy in modeling flow and chemistry coupling may produce only a small increase in the numerical results accuracy, despite the high modeling efforts and the increased computational cost.

Therefore, one must balance the theoretical and computer time effort needed to use a more general and sophisticated model against the expected accuracy of results.

This brings up the question of how to select appropriately the set of working hypothesis required to develop the mathematical model, so as to obtain accurate results with reasonably computational effort.

The hypothesis hereby considered are accordingly to the Newtonian fluids and modified Newton model.

In this chapter, we focus on two reference capsules as case studies (i.e. the Stardust and Apollo), which are analyzed and the results are compared to other similar codes.

Future improvements of the code consider the Busemann correction of the wall pressure (although the quality of results doesn’t necessary improve), the heat flux evaluation and the unsteadiness in order to enable the analysis of the hypersonic portion of trajectory and to assess the vehicle’s stability.

2. THEORETICAL SUPPORT AND MODELIZATION

In Fig. 1 is shown the Capsule Reference System CRS, which is used for the numerical computations.

The main goal is to compute: (a)- the pressure coefficient (1-2), taking into account the variation of the fluid properties through the means of the ratio of specific heat γ, and the velocity variation by the Mach number; (b)- the lift and drag coefficients (3), and (c)- the moment coefficients (4).

It is much convenient to calculate the equivalent axial and normal coefficients CA and CN (5). A correction for the back plate (5) was also considered.

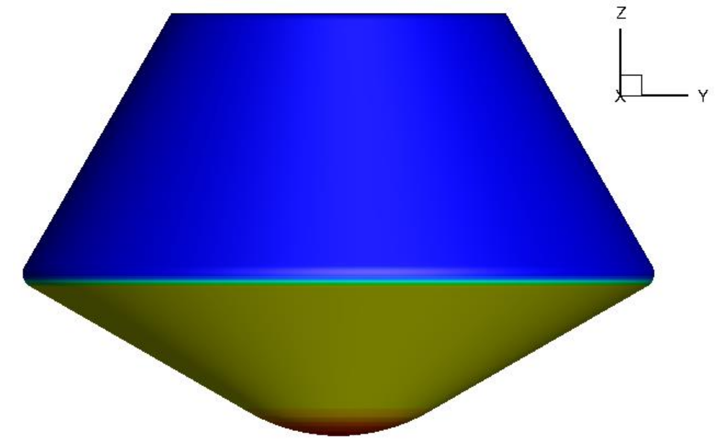


Fig. 1 – The Capsule Reference System CRS

$$Cp_{\max} = \frac{2}{M_\infty^2}\left(\frac{(\gamma+1)^{\frac{\gamma+1}{\gamma-1}} M_\infty^2}{2\left(2\left(2\gamma - \frac{\gamma-1}{M_\infty^2}\right)\right)^{\frac{1}{\gamma-1}}} - 1\right) \tag{1}$$

$$Cp = Cp_{\max}\left(\overline{e_V}^{T}\,\overline{n}\right)^2 \tag{2}$$

$$\begin{bmatrix} Cl_x \\ Cl_y \\ Cd \end{bmatrix} = \frac{1}{Aref}\int_A Cp \cdot \overline{n} \cdot dA \tag{3}$$

$$\begin{bmatrix} Cm \\ Cm_y \\ Cm_z \end{bmatrix} = \frac{1}{Aref \cdot Lref}\int_A Cp \cdot \left(\overline{r} - \overline{r}_0\right) \times \overline{n} \cdot dA \tag{4}$$

$$\begin{aligned} CA &= Cd\cos(\alpha) - Cl_x \sin(\alpha) \\ CN &= Cd\sin(\alpha) + Cl_x \cos(\alpha) \end{aligned} \tag{5}$$

$$\Delta CA = \frac{1}{M_\infty^2} - \frac{0.57}{M_\infty^4} \tag{6}$$

A FORTRAN code has been written in the object oriented manner, making benefit of an existing in-house library.

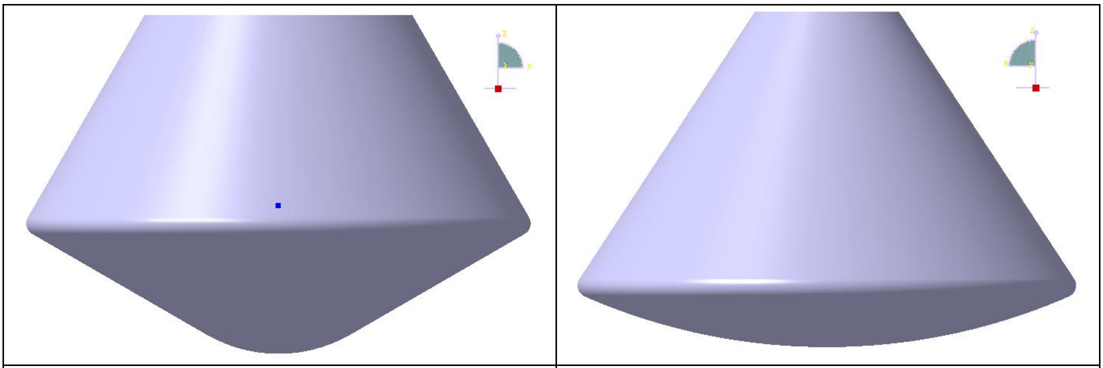
There are two input files: ***configuration*** and ***mesh***. In the configuration file the following data are introduced: mesh file name, method flag indicating basic or modified Newton, Mach number, altitude (to be furthered used), specific heat ratio, capsule radius used for reference area and reference length (diameter), set of incidences, and point reduction coordinates.

The mesh input file is the so-called NASTRAN bulk data, obtained from CATIA. The hybrid surface meshes are accepted.

The output files are ASCII Tecplot and Paraview (VTK) for each incidence angle and text file with all aerodynamic coefficients in both velocity and body coordinates.

3. STUDY CASES

The configuration of the reentry capsules as the study cases is shown in Fig. 2.



(a)- Stardust (b)- Apollo II

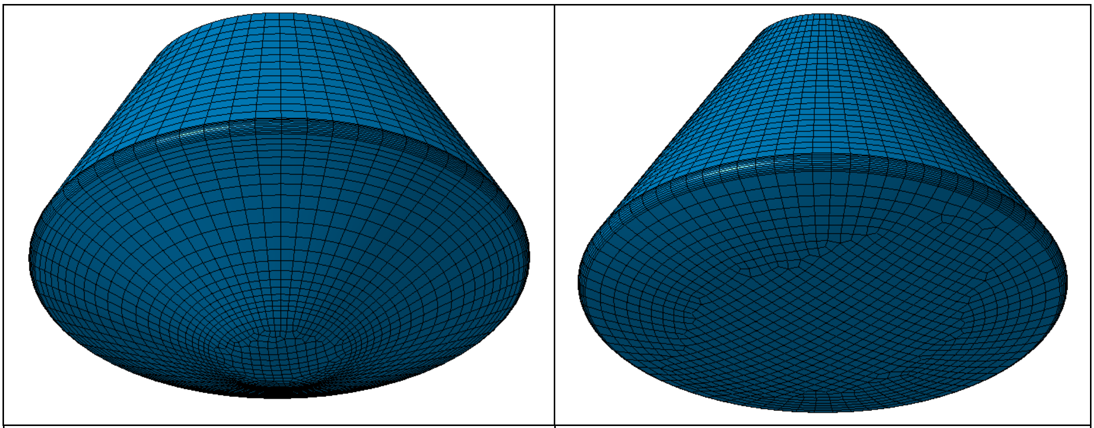
Fig. 2 - Validation Cases

The Stardust capsule has its forebody represented by a spherically-blunted 60 degree half-angle cone, with a 0.25 m nose radius; the shoulder radius is 0.02 m and the base radius is 0.41 m respectively.

For the beginning, there has been studied the 2D case; a straightforward method is employed, such that a CATIA model and its hybrid surface mesh are used as input.

Figure 3 displays a side view of the hybrid surface mesh.

The purpose of this study is to develop our own code, by using a method that provides good accuracy results in comparison to others, based on rather intricate models.



(a)- Stardust Capsule (b)- Apollo Capsule

Fig. 3 – Hybrid Surface Mesh

4. RESULTS AND CONCLUSIONS

The identification of the capsules' geometries and various results in the free literature [3], [5], [18] gave the possibility to validate the present code against similar codes or expensive CFD results.

It is clear that the results are nearly identical with those obtained with the basic Newton method [3].

Capsule	**CA**	**Remarks**
Stardust	1.5	Newton, Ref. [3]
0 deg	1.49	Current Newton code

Capsule	**CA**	**CN**	**Cm**	**Remarks**
Stardust	1.48	0.0422	-0.032	Newton, Ref. [3]
5 deg	1.48	0.04482	-0.03206	Current Newton code

Capsule	**CA**	**CN**	**Cm**	**Remarks**
Stardust	1.46	0.84	-0.064	Newton, Ref. [3]
10 deg	1.4534	0.08838	-0.06317	Current Newton code

Capsule	**CA***	**CA****
Apollo II	1.05	1.64
Apollo	1.4	1.64

* Results are from ref. [5], obtained by CFD, Mach=5.

** Results are computed with the developed code, using the corrected Newton method.

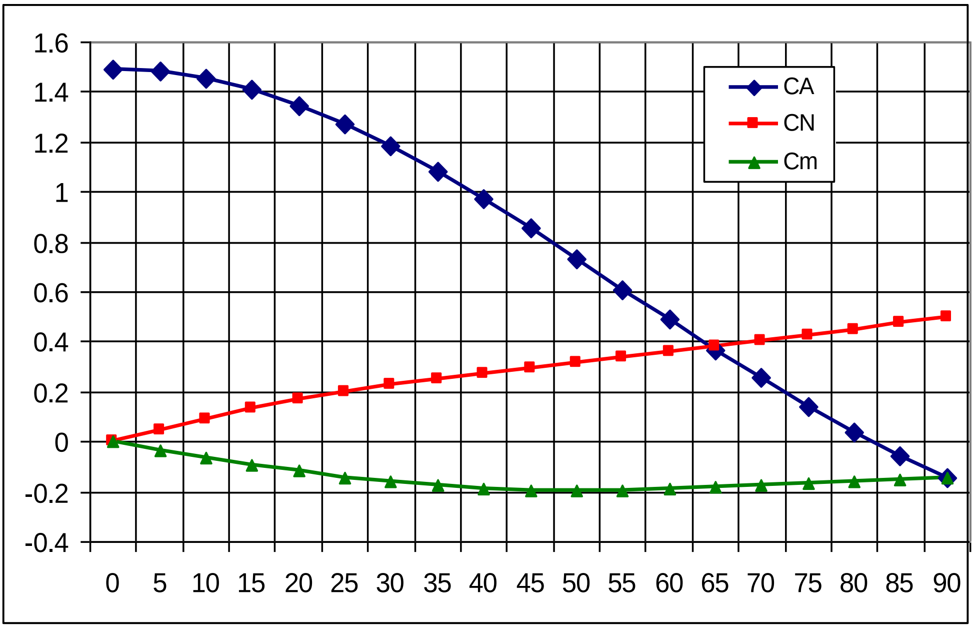


Fig. 4 – Stardust coefficients as a function of incidence

5. CONCLUDING REMARKS

The implementation is especially useful for educational purposes, giving the student a simple tool with a short path from CAD to results and post processing tools, in comparison with other classical fluid mechanics models/tools. The advantages are clear as expressed in terms of time:

- 10 min. to create the geometry in CATIA
- 15 min. to mesh
- 2 min. to prepare the job file
- few seconds to run

Future work will consist in the implementation of a heat transfer method and coupling with a dynamics model.

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