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STEERING MECHANISM AND EFFORTS ON THE NERVA SPACE LAUNCHER

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Abstract: *The steering mechanism of the Romanian project NERVA is a direct modification of the basic missile through the implementation of an additional gasdynamical driver to the existing quadruple aileron. The existing control ailerons will secure an aerodynamic control of the vehicle into the lower layers of the atmosphere only. After exiting the dense atmosphere, the gasdynamical steering vernier liquid propellant motors will gradually asume the dynamic control of the vehicle, under the action of the same pneumatic servo-mechanism presently used to steer the ailerons. Computations are necessary to evaluate the efforts required by the double drivers for the preliminary design of the new steering mechanism. First, numerical simulations of the airflow around the rocket's ailerons have been performed, in order to predict the driving moments versus the steering angle of the ailerons, during the most important phase of the flight, that begins with a velocity of Mach 2 at the altitude of 11 km. The computed magnitudes of the coefficient of the aerodynamic moment for the individual aileron are presented. Despite the large values of the lift forces, the couple around the middle axis is quite small.*

Key words: *supersonic flow, wing aerodynamics, computational fluid dynamics, aerodynamic control*

1. INTRODUCTION

Numerical simulations of the airflow around the *NERVA* control ailerons were performed and produced the values of the control lift force that appears at various tilt angles on the surface of the ailerons during the ascent flight into the atmosphere (Tache et al., 2009). It is emphasized during the development of the Romanian NERVA space launcher (Rugescu, 2008) that an additional control means is required when the vehicle exits Earth atmosphere. The same main pneumatic drivers that currently act the aerodynamic rudders of the rocket actuate the gas dynamic control used in this part of the flight. The design of the double flight control system, aerodynamic and gas dynamical, involves estimating the actual loads that have to be controlled by the pneumatic drivers. An aerodynamic couple has been determined, which appears around the steering axis of the aileron. Results of the computations by the research team of University "Politehnica" of Bucharest, by means of CFD simulations, are presented.

2. COMPUTATIONAL BACKGROUND

The size and geometrical aspect of the individual control aileron are shown in Figure 1. This "winglet" is built on a rhomboidal profile, which includes at the basis (next to the fuselage) a rectangular core. All the facets of the aileron are planar and entirely symmetrical in respect to the profile chord. The aerodynamic torque is given by the asymmetrical shape of a profile and by the lift force moment in respect to the axis of resolution (pole). Consequently, a symmetrical profile gives no aerodynamic torque and in this case, at supersonic speed and on zero angle of attack, the coefficient of the aerodynamic moment C_{m0} is nil (Carafoli, 1969; Seebass & Woodhull 1998).

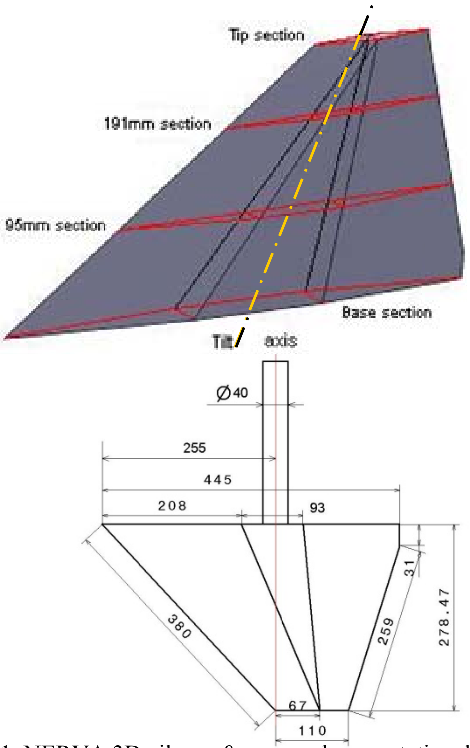

Fig. 1. NERVA 3D aileron & assumed computational sections

According to the linear theory of Ackeret, at small α angles of attack, the lift and moment coefficients are given by

$$C_L = \frac{4\alpha}{\sqrt{M_\infty^2 - 1}} \qquad C_m = \frac{1}{2}\frac{4}{\sqrt{M_\infty^2 - 1}}\frac{S_1 - S_2}{c^2} + \frac{1}{2}\frac{4\alpha}{\sqrt{M_\infty^2 - 1}} \tag{1}$$

where M_∞ is the flight velocity, S_1, S_2 are the upper and lower winglet surfaces and c is the chord (Carafoli 1969).

Ascent parameters of the space rocket have been computed and the aerodynamic simulations were set for a convenient flight altitude and local velocity. The coefficients for lift and moment become

$$C_L = \frac{4\alpha}{\sqrt{3}} = 2.309\alpha \qquad C_m = \frac{1}{2}\frac{4\alpha}{\sqrt{3}} = 1.155\alpha \tag{2}$$

The pole is set at the leading edge of the airfoil and the positive sign of moments means decreasing the angle of attack. It results that the focus of the symmetrical, supersonic wing is at its middle point, the lift location. The values given by the simplified theory are compared below with the viscous flow computations. The 3D aileron is a little bit swept backward and the middle points of the profiles at various sections are not aligned along a unique normal axis in respect to the fuselage. In other words, the line of focuses along the profiles is not normal to the fuselage. The image of the aileron is given in Figure 2. The tilting axis is visible in detail in Figures 1-2 and the computational problem is for the driving torque required to reliably tilt the aileron during the low atmospheric flight.

Fig. 2. Aileron in neutral position on fuselage and cut-away

The numerical simulation refers to an altitude of *11km*, with a travelling speed of *Mach 2*, while the surrounding pressure and temperature are *22632 Pa* and *216.65 K*, respectively.

3. RESULTS OF CFD SIMULATIONS

The following values for the aerodynamic coefficients of lift and moment in respect to the axis of tilt drawn in Figure 1 were found, as reproduced in diagrams 3 and 4.

The values of the reduced coefficients are given versus the angle of incidence. Values up to the maximal allowable tilt of 28 degrees were computed. They agree well with the theoretical formulae (2). The four separate sections are fairly converging.

For CFD simulations, four different equally spaced sections have been used, along with a 3D model of the complete aileron, thus being able to study the 2D air flow at different locations on the wing's span and also providing an overall image of the three-dimensional flow pattern.

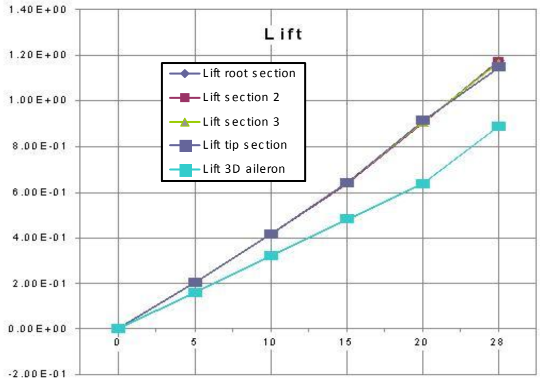

Fig. 3. Diagram of the computed lift coefficient of the aileron

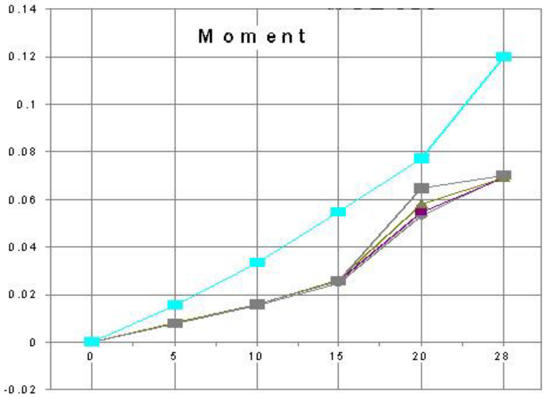

Fig. 4. Diagram of the computed moment coefficient

While keeping the flow parameters to the values presented above, the angle of incidence has been varied from *0* to *20 degrees* by *5-degree* increment step with the additional value of the maximal pitch of *28 degrees* for a complete covering. A total of *24* two-dimensional cases and *6* three-dimensional cases were simulated with the commercially available software *Fluent* (FLUENT INC., 2009). The *k-omega* turbulence model was adopted as more appropriate for the simulation.

The use of a *k-omega* formulation in the inner parts of the boundary layer makes the model directly usable all the way down to the wall through the viscous sub-layer. The model switches to a *k-epsilon* behavior in the free-stream and thereby avoids the common *k-epsilon* problem that the model is too sensitive to the inlet free-stream turbulence properties. Authors who use the *k-omega* model often praise it for its good behavior in adverse pressure gradients and separating flow. Nevertheless, the *k-omega* model produces a bit too large turbulence levels in regions with large normal strain, like stagnation regions and areas with strong acceleration. This disadvantage is less pronounced however than that involved when a normal *k-epsilon* model is used (CFD-Wiki, 2009).

4. CONCLUSION

A very small coefficient of aerodynamic torque is encountered through CFD simulations, in agreement with the theoretical values of the moment in respect to the middle axis of the symmetrical profile. In fact, with drag by viscous effects and due to the sweptback geometry for the aileron, a small, positive aerodynamic moment appears. The location of the focus for the entire, 3D aileron is not yet specified, although all the geometrical and mechanical results suffice to determine its position in space. Its locus is important for positioning of the steering axis, which must be set as close as possible to the focus of the 3D profile to minimize the steering couple for the driving mechanism. The driving mechanism will impart some of the power for driving the gas dynamical thrusters, which fortunately require a very low driving moment.

The differences between the coefficients of the individual profiles at the computational sections referred to in Figure 1 are due to the differences in the computational conditions. While for the 2D profiles the flow is ideally planar, for the 3D model the side flow and marginal losses are allowed, fact that diminishes lift. Same applies for the moment coefficient.

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