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BANK BOOSTERS DE-SYNCHRONIZATION OF THE ORBITAL LAUNCHER NERVA

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Abstract: *The performance enhancement required by the original military vehicle in order to transform it into the NERVA orbital launcher for small payloads is a space project sponsored by the Romanian Ministry of Education, Research, Youth and Sports through the contract 82076 along a four year development period. It involves, among other main modifications, the accomodation of two additional solid propellant motors as side, or bank boosters, in parallel to the central, existing SRM. In this manner the starting thrust of the NERVA launcher is increased threefold. The major problem involving the parallel boosters is related to the de-synchronization of the thrust and a solution is forwarded to mitigate the potential effects of this de-synchronization of the two bank boosters. The transversal overloading of the inter-stage fixture and of the second stage structure must imperatively be avoided. A description is given of the staging sequence of the orbital launcher and some design and manufacturing measures are described that minimize these over-loading effects of the first stage SRM-s. The actual stage of development of the NERVA project is presented in short, including observations on the burnout roll effects of the central SRM of the vehicle.*
Key words: *Rocket vehicles, flight dynamics, rocket flight*

1. INTRODUCTION

A large performance increment of the rocket carrier vehicle is required in order to extend the 2600 m/s ideal velocity of the source military vehicle (Zaloga, S. 1989) to 9500 m/s for the NERVA satellite launcher. The first major extension is in the tankage volume of the second stage, i.e. in the total mass of this stage. To preserve the well-proven lift-off flight stability of the source vehicle, the starting thrust of the first stage is also increased threefold, while a similar launching rail will be used at lift-off to guide the rocket during the first stage initial burn. The existing single solid booster (e-site 2010) is thus augmented with two extra SRM-s attached aside in a planar configuration. The small but inevitable delay at ignition of the individual SRM-s creates momentary, transverse reactive forces at lift-off that have to be absorbed by the new launch rail. Three other complementary measures are implemented to level the possible small imbalance of the bank thrusts and to minimize the momentary transversal torque, created by the burning time de-synchronization at booster burnout (Jeyakumar et al., 2005). One of the solutions involves a complex thrust frame mechanism that connects the first two stages and removes the non-depleted bank boosters from the second stage, during the final take-off thrust. Numerical evaluation of the efficiency is provided (Constantinescu et al., 2009).

These quite extensive modifications of the original rocket weapon are depicted in Fig. 1. Three similar boosters are required to secure the normal thrust enhancement of the first stage. The means of providing these three SRM boosters with a smooth and reliable frame for transfer of thrust to the upper stage structure is considered, with provisions for an equally reliable relase of the boosters at the first detection of cut-off.

This could occur in any of the three SRMs. A mechanism of stage separation is involved (Fig. 2.).

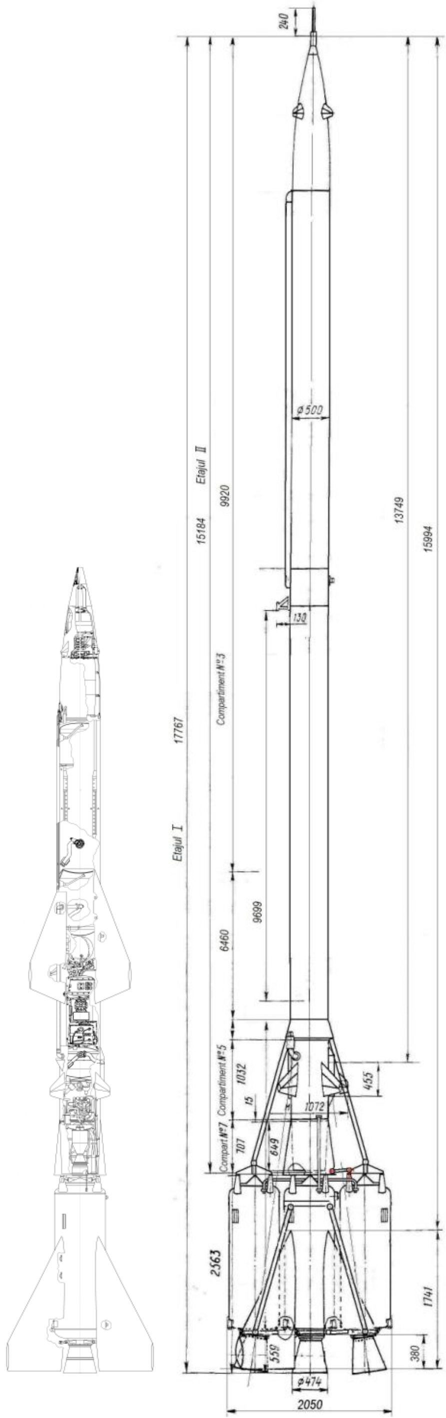

Fig. 1. The military missile and the new NERVA launcher

2. DE-SYNCHRONIZATION THEORY

As an extremal case of study, the situation is considered when one of the side engines is working at full thrust and the other one is completely stopped. This extreme situation may occur for a very short time period, called de-synchronized period, either after ignition, due to the different time delays of the igniting system, or at burn-out, due to the initial delay and to inherent differences in the burning time of the SRMs.

For the specific construction of the PRD-56 solid motor, which incorporates 12 quasi-idential solid propellant cyllindrical grains, this large number of propellant cartridges statistically mitigates the differences in the burning time betweeen the individual grains, and, consequently, between the burning time of the entire SRMs. The tranfer of the gasdynamical thrust to the structure along the stings is given in Fig. 2 and produces the structure bending (Fig. 3).

The physical effect of this imballance is represented by a momentary bending and angular acceleration of the rocket frame, due to the inherent dissymetry of the aerodynamic loads along the frame (Fig. 3). Remaining within the realm of the plane-parallel motion, this motion is described by the three degrees of freedom equation (Staicu, 1998, Ch. 18)

$$\frac{d}{dt}\mathbf{K}_A + \mathbf{\Omega}\mathbf{K}_A = \sum_{i=1}^{n} \mathbf{A}\mathbf{R}_i^0\mathbf{A}^T\mathbf{F}_i \qquad (1)$$

where $\mathbf{K}_A$ is the dual vector of the kinetic moment in respect to a non-moving referential $\{x_A, A, y_A, z_A\}$, $\mathbf{\Omega}$ is the absolute, dual angular velocity of the moving body of the vehicle in flight, A is the quadruple matrix of transfer from the mobile body (referencial) into the fixed referential and $\mathbf{R}^0{}_i$ is the dual position vector of the dual external forces F_i. A number of n independent and concentrated forces are considered as applicable in this case. By definition, each dual vector is a three by three-column matrix with specific determination in each case. The general equation of motion (1) render simple components (Roshanian and Talebi 2008) when the distribution of forces in Fig. 3 is considered. It is more useful to describe the dynamical loading by writing the dynamic equation of motion with respect to a convenient, mobile point O, related to the flying body, when the equation of motion gets the known matrix form

$$\mathbf{M}_O\frac{d}{dt}\mathbf{\Omega} + [\mathbf{\Omega}]\mathbf{M}_O\mathbf{\Omega} = \sum_{i=1}^{n}\mathbf{X}_i\mathbf{F}_i - m\mathbf{A}X_O^0\mathbf{A}^T[\mathbf{\Omega}]\mathbf{X}_C \qquad (2)$$

where $\mathbf{M}_O$ is the inertial tensor of the mass and $[\mathbf{\Omega}]$ the dual matrix of the angular velocity (Staicu, 1998, Ch. 18).

The general equation (2) may be resolved into the kinetic impulse and the kinetic moment. In regard to Fig. 3 the main equation under attention is

$$\int_0^l \mathbf{x}\wedge(\mathbf{a}_O + \boldsymbol{\varepsilon}\wedge\mathbf{x} + \boldsymbol{\omega}\wedge\boldsymbol{\omega}\wedge\mathbf{x})\,dm = \delta\mathbf{x}_c\wedge\mathbf{F}_c + \delta\mathbf{x}_b\wedge\mathbf{F}_b + \mathbf{x}_a\wedge\mathbf{R}_a \qquad (3)$$

where $\boldsymbol{\varepsilon}$ is the angular acceleration in a current point, δ are the deviations of the central and bank thrusts and index "a" is for aerodynamic efects, considered as concentrated forces $\mathbf{R}_a$.

The distributed forces of inertia and the concentrated thrust, plus the aerodynamic effects, produce the critical case.

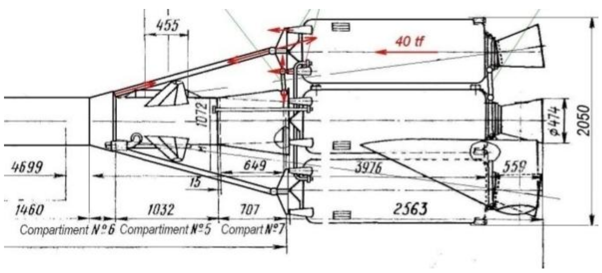

Fig. 2. Transfer of thrust to upper structure along the stings

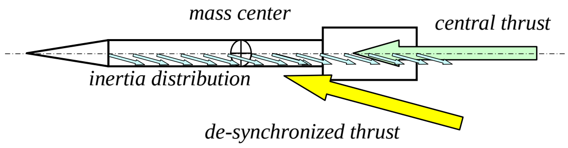

Fig. 3. Load and computational de-synchronization model

3. RESULTS AND TECHNOLOGICAL ASPECTS

The bank thrust de-synchronization is mitigated by the orientation of the bank thrust through the mass center of the vehicle through tilted nozzles. Only translational effects remain. The angular acceleration is induced by the thrust imbalance (Roshanian and Talebi 2008). When this time is reduced to one tenth of a second, the angular acceleration is

$$\varepsilon = \frac{\delta x_c F_c + \delta x_b \wedge F_b + x_a \wedge L_a}{J_O} \qquad (4)$$

With maximal values for δx_C and δx_b of 0.002 meters and considering the maximal thrust of the SRM of 58 metric tons, disregarding the aerodynamic effects in the first approximation and employing a value of 1×10^4 kg×m^2 for the moment of inertia of the body (freezing assumption), a value of 0.232 rad/second^2 angular acceleration occurs. Considering the time of action of 0.1 seconds, this angular acceleration accumulates a total angular velocity of 0.0232 rad/second ().

4. CONCLUSION

The mechanical load and stresses during thrust imbalance is a critical computational case. They may produce large local stresses with devastating effects upon the wall structure of the vehicle, where the hidrostatic preexisting loading is an extra factor of concern. Some known rocket launch failures were induced by the thrust imbalance and desinchronization in the burning time of the SRM boosters into the cluster. Thus the problem of predicting the actual dynamics is important.

The method of numerical simulation here introduced proves being decisive in resolving the transients of thrust and their mechanical effects upon the vehicle body.

5. ACKNOWLEDGEMENTS

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