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HALF-ORBITAL NERVA LAUNCHER BLOCK FOR SMALL LEO SATELLITES

R. D. Rugescu¹, D. Mortari*, I. Farcasanu[§], V. Martin[†], E. Teujan[‡], M. D. Ionescu[#],
D. Dragomir[◇]

¹University "Politehnica" of Bucharest, Romania, *Texas A&M University US, [§]Electromecanica SA Ploiesti, Romania, [†]ELAROM Romania, [‡]Aerofina SA Romania, [#]COMOTI NRTDI Romania, [◇]Flight Test Center, Craiova Romania
rugescu@yahoo.com

ABSTRACT

The ADDA and UPB teams for space technology develop the immediately approachable Romanian NERVA orbital launcher. The NERVA vehicle is a small, readily available and low cost means to demonstrate the feasibility to achieve secured sub-orbital flights with a final velocity of up to half of the local orbital velocity, at low satellite altitude, by the re-conversion of retired soil-air SA-2 Guideline systems, now obsolete in Romania. The development plan involves a considerable raising of the final flight altitude and velocity from the basic soil-to-air conventional vehicle to a half-orbital velocity vector. A series of simple but decisive design improvements are implemented. For example, a new, superior three-axes attitude control system for the launching vehicle is provided, which may supply orbital altitude and velocity requirements with high accuracy. The management plan for the early development of the NERVA half-orbital velocity block is presented that keeps the basic solid and liquid motors unchanged, involving point improvements in the structure and control systems of the vehicle. The purpose of the research is to build and demonstrate a laboratory model of the new vehicle and of the functionality of the flight control system as a bench-top demonstrator. The development is supported by the Romanian Ministry of Education and Research within a three-years grant and is performed by a consortium of six research and industry partners.

INTRODUCTION

With the growing interest in low cost vehicles for responsive space access, the number of small to medium sized orbital transporters is increasing, under the name of *small satellite launchers*. Some private companies with the capability of developing cheap space transporters are already raising, only to mention the international¹ "Sea Launch" and US "SpaceX"², "Orbital"³, "t/Space"⁴ or the Russian "Air Launch Corporation"⁵. They entered this new and

promising market. Claimed for long as the optimal solution for launch into Earth orbit, the return to expandable launchers was bolstered by the final failure of low cost, secure Space Shuttle systems in US and Russia. Other similar reusable orbital systems from Japan, China and Europe had also been cancelled due to uncertainties exhibited during the American and own national developments with reusable transporters. One of the renewed solutions, the airplane satellite launch, first sought in early '50s through the *Pilot* project, ended in failure⁶. It only became operational after four

decades with *Pegasus* three-staged launcher, a private system from Orbital⁷, with 38 successful missions since 1993. Small vehicles were considered in Spain by "INTA", within the AQUARIUS air-launch project. Very light structure solid rocket engines of Spanish technology are desired and the Eurofighter as an air launch platform⁹.

The project of ADDA SME (Association Dedicated to Development in Astronautics) is aimed at building a ground launch cheap vehicle by intensively using reconverted military small rocket systems of SA-2 type that became available in Romania from air defense applications. The involvement of University "Politehnica" of Bucharest (UPB) in FP7 European Space priority projects motivates the development of the NERVA launcher¹⁰ for PUBSAT. It consists of a readily available, low cost demonstrator for achieving half of the local orbital velocity at 100 miles altitude for the three-axes controlled (3AC) satellite. The improved rocket transporter stands within the Romanian technology frames, addressed through a high level industrial consortium (Electromecanica, Aerofina, Powders Factory in Fagaras and ELAROM), with UPB as project coordinator. The foreground of the NERVA vehicle is the soil-air SA-2 Guideline weapon, now obsolete in Romania, subjected to a precisely controlled re-conversion. SA-2 is a derivation in fact of the famous *Rheintochter* missile, successfully developed at Peenemunde in early 1945 by the rocket team of Wernher von Braun. The new NERVA stands as a peaceful renovation of that brilliant work, transforming soil-to-air missile into a high performance orbital vehicle, perhaps the first orbital project developed from such a conventional rocket. Another first is the low-mass 3AC of PUBSAT. The expertise of the ADDA SME (Association Dedicated to Development in Astronautics) and the existing capabilities of the industrial partners give confidence in this project¹⁷. An upper stage with the performance of 5000 meters per second ideal velocity is at the limit of the current Romanian rocket technology. All align into building a cheap, ground launch vehicle by a minimal modification of the SA-2 rocket system. This requires however a drastic improvement of the structural efficiency of the SA-2 Guideline system, to accommodate higher thrust enhancement of the solid motor (SM) booster, thrust vectorization of the liquid

motor (LM) and lightweight sustainer structure for the second stage, with highly extended propellant tanks and lightweight guidance. They are a continuation of the NERVA study of the author, where relative effects of structure and specific impulse enhancements were analyzed¹⁰. The considerations observed are:

- preserve fairly unchanged the current first stage solid motor construction;
- accept a number of extra boosters in a cluster around the original single booster;
- preserve the second stage liquid rocket engine construction fairly unchanged;
- sensible extension in the combustion time of the second stage liquid motor;
- lightweight liquid propellant motor nozzle extension for exo-atmospheric flight;
- allow for a sharp lengthening of propellant tanks of the second stage;
- remove all current military equipment and hardware;
- remove the fixed fins of the second stage;
- provide extended tankage, liquid motor gimbals and reinforced structure;
- direct the action of the stirring actuators from the fins to the liquid motor;
- locate the unique flight control equipment into the satellite module.

The prediction of the available performance is performed by computer simulations, proving the feasibility of the NERVA vehicle as an orbital system.

THE ASCENT TRAJECTORY

The simulated trajectory conveniently supports injection into a low orbit at the altitude of 160 km through a final boost by a third stage, that adds a velocity supplement Δv to the apogee remainder velocity of the carrier vehicle, up to the local circular velocity. The Δv grows smaller with increasing carrier power, meaning that a maximal horizontal apogee velocity is required for the improved NERVA carrier. Additional SM-s in a cluster induces sensible velocity savings for the third stage, as numerical simulations of the ascent flight show.

Trajectory simulations were performed based on a planar local inertial model, into a geographic referential. This allows considering the gravitational field of the Earth as spherical and quasi-spherical and the Earth under its diurnal rotation. Computation had given good results as compared with known data for existing vehicles. Gravity turn

trajectories are always assumed, along the trans-atmospheric flight to minimize the drag and along the exo-atmospheric ascent to maximize the thrust output. These paths involve a non-vertical launch and are described by four dependent variables, for example the velocity magnitude v , its inclination above the starting horizontal θ , the instant distance to the Earth center r and the central angle of view of the path φ . Into a simplified scheme with non-rotating Earth and constant gravitation, the motion always remains in a plane and only depends on three dependent variables¹⁴. The downrange distance x_A or the equivalent angle φ does not appear as a defining variable for the constant g trajectories. It is only the inclusion of the spherical Earth that obeys to introduce the fourth parameter x_A .

The four corresponding first degree ODE-s that govern the motion are

$$\begin{aligned} \frac{dv}{dt} &= -C \frac{d \ln \mu(t)}{dt} - \frac{R(r - R_E, v_r)}{\mu(t)} - K_E \frac{\sin(\theta + \varphi)}{r^2}, \\ \frac{d\theta}{dt} &= -g(r) \frac{\cos(\theta + \varphi)}{v}, \\ \frac{dy_A}{dt} &= v \sin \theta, \\ \frac{dx_A}{dt} &= v \cos \theta. \end{aligned} \quad (1)$$

The equations are written within the inertial frame $\{Ax_Ay_Az_A\}$, bound to the launching site A, with local vertical as axis y_A and local horizontal x_A directed towards the azimuth of the launch. Due to the specific geography of the launch site and launch direction, located on the southern Romanian border on the Black Sea west bench, the launching azimuth is considered to be equal to 90° (Eastern direction). The local Earth peripheral velocity of rotation of 328 m/s at launch latitude is thus fully imparted to the spacecraft at injection. In the above equations C stands for the vacuum specific impulse of the rocket engine, μ for the variable, instant mass ratio of the vehicle

$$\mu(t) \equiv \frac{M_0}{M_0 - M_p} = \frac{M_0}{M_f}$$

where M_p is the mass of consumed propellant, subtracted from the initial mass M_0 to render the final mass of the vehicle after burn-out M_f , R is the retardation (the sum of the aerodynamic drag D and the base thrust

induced drag B on the nozzle exit¹³), v_r is the magnitude of vehicle velocity relative to the local atmosphere and K_E is the gravitational constant of the Earth.

The following restrictions are added to the previous equations regarding the mass consumption law and geometrical connections between the variables,

$$\begin{aligned} \mu(t) &= \mu_0 - b \cdot t, \\ \varphi &= \arg \tan \frac{x_A}{y_A + R_E}, \\ r^2 &= x_A^2 + (y_A + R_E)^2. \end{aligned} \quad (2)$$

A constant mass flow rate b is considered. Results of numerical integration with two different routine codes, created by UPB to assess the accuracy, for different vehicle configurations, are given in Table 1 and Table 2.

BASIC CONFIGURATION V.11

To mark a reference basis, the ascent motion was first simulated for the basic SA2 configuration. This source vehicle is a two-staged rocket system, involving a SM booster stage and a LM sustainer, turbo-pump stage. Its deliverable ideal velocity in a free space of 2500 m/s was presented previously¹⁰. Now the real flight characteristics are revealed, assuming a non-lift, gravity-turn trajectory that follows an initial start from a short guiding rail of the mobile ground launcher at an elevation angle close to the vertical ($\theta_0 \approx 86^\circ$), in order to exit the atmosphere fast towards a maximal pick altitude of 131 km . The launching pad ensures an exit velocity of 50 m/s from the rails, to secure the aerodynamic stability of the initial flight. The high thrust enhancement provides a fast increase in velocity during the first stage boost. It is noted that the standard SA-2 vehicle is provided with a considerable take-off thrust-to-weight ration of 15, meaning that the structure of the second stage is designed to face high extra loads during the initial boost with ease. This allows considering additional boosters as easily acceptable, up to a limit imposed by the admissible structure overloads, due to even much higher accelerations during the boost phase.

The start from the tethered launcher with 10 meters rails long lasts for some 0.4 seconds of the total burning time of 3.6 seconds of the PRD-18 booster SM. During the first stage phase the large four fixed fins,

fastened to the SM (Fig 4), secure an acceptable aerodynamic stabilization of the vehicle, augmented by the small, four rotating fins of the second stage. The gravity turn flight plan is controlled by the auto-pilot (inertial-optical) included in the payload. The 3.6 seconds of high boost are consumed up to 920 meters altitude when the speed is 514 m/s, slightly supersonic (M 1.5) and the ignition of the second stage LM is initiated, with subsequent disconnection of the first stage. The empty booster falls within 1412 meters off the launch site, an acceptable clearance for the safety requirements. This is consistent with military regulations of SA-2 launches. The RADAR guidance during the experimental launches of the basic NERVA configuration is replaced by total auto guidance through the navigation platform, although the presence of all standard military equipment, excepting the warhead, is preserved. This way the mass characteristics and centering are preserved. The flight profile of the basic, inertially guided NERVA, is given in Fig. 1.

The basic NERVA is a useful test-bed for the novel 3AC avionics with local vertical pointing, in advance of the improved NERVA propulsion and independent of it. Attitude control during atmospheric and exo-atmospheric ascent and during third stage burn can be suitably tested during over four minutes of exo-atmospheric weightlessness, close to the eventual real climb to orbit. The exo-atmospheric span is given in Fig. 1. Payload recovery is also considered^{14, 15}.

Within the first flights of the basic NERVA V.11 the second stage fins will be used unchanged, to secure a convenient stability without thrust vectorization.

PERFORMANCES OF THE VERSIONS

Three two-stage improvements of the standard SA2 rocket were considered, all involving identical, longer second stage, with extended propellant capacity¹⁰, and three or seven first stage SM-s respectively. Each SM delivers 360 kN of sea-level thrust¹¹ for a short 3.7 seconds burn. The versions are V.12 (one SM), V.32 (three, parallel SM-s) and V.72 (seven SM-s). Computed data for a 160-km orbit are given in Table 1. A similarly low orbit was used in the early Mercury manned orbital program of 1960s.

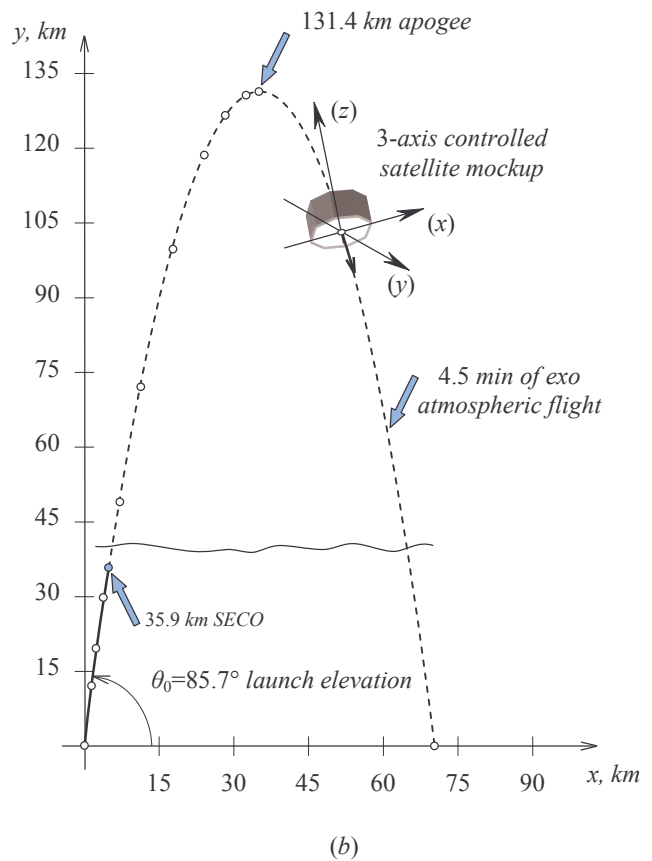


Fig. 1. Exoatmospheric trajectory

VERSION V.12.

This simple version involves modification of the second stage only. Military equipment of 400 kg in this stage is removed and the gross mass of the second stage is increased from 1390 kg to 2400 kg, including a payload of 75 kg and largely extended propellant tanks. Due to the smooth flight trajectory, the propellant pendulum-type suction pitheads and anti-sloshing diaphragms are removed from the tanks. The gimbal mounting of the LM involve an optimal choice between a head spherical bearing and a Cardano cross-link. A new and improved mass ratio equal to 4.138 can thus be achieved.

The thrust-to-weight ratio of 1.5 balances well between the requirement for a massive second stage and a fast climbing rate. The basic LM S2.720 of the second stage, provided with a dual thrust construction, will be used at the maximal thrust of 35 kN. Its combustion time of 22-48 seconds should be extended up to a total of 113.5 seconds to consume the larger propellant quantity of 1820 kg.

Table 1

Characteristics and potential performances of NERVA vehicles

| First stage: | | V.11 | V.12 | V.32 | V.72 |
|--|--|---|-------------|-------------|-------------|
| Lift-of elevation, $\theta_0=$ | | 85.7° | 75.923° | 62.39° | 54.61° |
| Lift-of mass, total, $M_0=$ | | 2400 kg | 3410 kg | 5430 kg | 9470 kg |
| Structure mass, $M_{s1}=$ | | 400 kg | 400 kg | 1200 kg | 2800 kg |
| Propellant mass, $M_{p1}=$ | | 610 kg | 610 kg | 1830 kg | 4270 kg |
| Total mass, booster only, $M_{01}=$ | | 1010 kg | 1010 kg | 3030 kg | 7070 kg |
| Payload mass (2nd stage), $M_{02}=$ | | 1390 kg | 2400 kg | 2400 kg | 2400 kg |
| Empty mass, 1st stage, $M_{11}=$ | | 1790 kg | 2800 kg | 3600 kg | 5200 kg |
| Mass ratio, booster alone, $\mu_{01}=$ | | 2.525 | 2.525 | 2.525 | 2.525 |
| Mass ratio, global 1st stage, $\mu_1=$ | | 1.341 | 1.218 | 1.508 | 1.821 |
| Time spent on launcher, $t_{00}=$ | | 0.378 s | 0.605 s | 0.313 s | 0.232 s |
| Mass ratio spent on launcher, $\mu_{00}=$ | | 1.031 | 1.030 | 1.030 | 1.030 |
| Mass ratio on launcher exit, $\mu_{11}=$ | | 1.301 | 1.182 | 1.464 | 1.768 |
| Lift-of thrust, $T_{01}=$ | | 360 kN | 360 kN | 1080 kN | 2520 kN |
| Thrust enhancement, $n_0 \equiv T_{01}/G_0=$ | | 15.0 | 10.6 | 20.3 | 27.1 |
| Burning time 1st stage, $t_1=$ | | 3.7 s | 3.7 s | 3.7 s | 3.7 s |
| Specific impulse, sea level, $I_{sp1}^0=$ | | 2115 m/s | 2115 m/s | 2115 m/s | 2115 m/s |
| Specific impulse, vacuum, $I_{sp1}=$ | | 2257 m/s | 2257 m/s | 2257 m/s | 2257 m/s |
| Ideal velocity 1st stage, $W^*_1=$ | | 663 m/s | 495 m/s | 928 m/s | 1355 m/s |
| Real end velocity 1st stage, $v_1=$ | | 514 m/s | 346 m/s | 716 m/s | 1022 m/s |
| Real altitude 1st stage, $h_1=$ | | 923 m | 590 m | 1091 m | 1407 m |
| Second stage: | | Standard | Long | Long | Long |
| Initial mass, 2nd stage only, $M_{02}=$ | | 1390 kg | 2400 kg | 2400 kg | 2400 kg |
| Structure mass, $M_{s2}=$ | | 200 kg | 505 kg | 505 kg | 505 kg |
| Propellant mass, $M_{p2}=$ | | 715 kg | 1820 kg | 1820 kg | 1820 kg |
| Payload & equipment, $M_L=$ | | 475 kg | 75 kg | 75 kg | 75 kg |
| Empty mass, 2nd stage, $M_{12}=$ | | 675 kg | 580 kg | 580 kg | 580 kg |
| Start-up thrust, $T_{02}=$ | | 35 kN | 35 kN | 35 kN | 35 kN |
| Thrust enhancement, $n_0=$ | | 2.570 | 1.49 | 1.49 | 1.49 |
| Mass ratio, 2nd stage, $\mu_{02}=$ | | 2.059 | 4.138 | 4.138 | 4.138 |
| Burning time 2nd stage, $t_2=$ | | 44.6 s | 113.5 s | 113.5 s | 113.5 s |
| Specific impulse, sea level, $I_{sp1}^0=$ | | 2187 m/s | 2187 m/s | 2187 m/s | 2187 m/s |
| Specific impulse, vacuum, $I_{sp2}=$ | | 2670 m/s | 2670 m/s | 2670 m/s | 2670 m/s |
| Speed increment 2nd stage, $\Delta V_2=$ | | 891 m/s | 2666 m/s | 2736 m/s | 2711 m/s |
| Ideal velocity 2nd stage, $W^*_2=$ | | 1928 m/s | 3793 m/s | 3792 m/s | 3792 m/s |
| Global: | | (Circular 160 km velocity $v_0=7489.0$ m/s) | | | |
| Gross initial mass, $M_0=$ | | 2400 kg | 3410 kg | 5430 kg | 9470 kg |
| Burn-out altitude, $h_C=$ | | 35.9 km | 71.7 km | 81.1 km | 85.8 km |
| Downrange cut-of position, $s_C=$ | | 4.8 km | 102.5 km | 143.7 km | 173.1 km |
| Cut-of elevation, $\theta_C=$ | | 80.8° | 23.7° | 18.8° | 16.4° |
| Real cut-of velocity, $v_C=$ | | 1405 m/s | 3012 m/s | 3452 m/s | 3733 m/s |
| Ideal velocity, total, $W^*=$ | | 2591 m/s | 4287 m/s | 4720 m/s | 5147 m/s |
| Coast apogee, $h_{max}=$ | | 131.4 km | 160.0 km | 160,0 km | 160,0 km |
| Downrange at apogee, $s_{max}=$ | | 34.9 km | 494.0 km | 596.1 km | 664.2 km |
| Remaining apogee velocity, $v_D=$ | | 214 m/s | 2716 m/s | 3226 m/s | 3538 m/s |
| Impact range, $L_E=$ | | 70.2 km | 1018 km | 1235 km | 1379 km |
| Impact velocity, $v_E=$ | | 458 m/s | 353 m/s | 329 m/s | 318 m/s |

In the present study the original IRFNA nitric acid oxidizer (27% N_2O_4 +73% HNO_3) and German fuel Tonka-250 (50% Triethylamine+50% Meta-Xylidine) are preserved, to avoid changes in the propulsion system. This meets the demands for low development costs and acceptable reliability. The above given trajectory allows injecting a third stage into a low orbit at 160 km. Adding there a $\Delta v= 4773 m/s$ for that third stage the circular orbit will be successfully achieved.

VERSION V.32.

Without other modifications in the second stage, two extra SM-s are mounted in parallel to the existing booster, to extend the starting thrust to three times that of the present, standard rocket booster. The new first stage is thus formed of three similar PRD-18 motors with almost identical mass and thrust characteristics. Subsequent modifications are inevitable however, regarding the connecting means between the two stages of the rocket, a new, hot gas duct communication between the three thrust chambers for pressure balance and new, inclined nozzles on the lateral engines for thrust alignment. This new configuration is given in Fig.2. They also involve a reduction in the number of fins, the large ones on the second stage proving unnecessary and being removed. Thrust vectorization solves the attitude control on the second stage powered flight, most of which is performing at high altitude with too thin an atmosphere, inasmuch of the eventual third stage, which runs in an almost absolute vacuum. The original solid booster was designed with a modest technology, according to the needs of the SA application. It has a poor mass ratio of 2.525 relative to the high demands as a space launcher. It is yet the largest solid rocket motor developed during WW-2. The blend A-100 triple-base propellant (NC-NG-DNT + additives) supplies a sea level specific impulse of 2200 m/s at a convenient burn temperature of 2500°K. Upgrading is envisaged¹⁶.

NERVA VERSION V.72

The extreme version involves a total of seven, clustered SM-s, the maximal allowable geometric extension. The resulting vehicle has a mass, thrust characteristics and computed performances as given in the last column of Table 1, when the launch takes

place under an elevation angle of $\theta_0=54.61^\circ$ to achieve a 160-km orbit from sea level start. The lift-of thrust is raising to 210 metric tons, inducing a maximal acceleration of 26g, at the limit of the structure tolerance of the second stage. This only adds 165 m/s to the apogee velocity, perhaps too small to justify this tremendous extension. An artist image of the lift-of is given in Fig. 2.



Fig. 2. V.72.lift-off, artist's concept.

THE THIRD STAGE

A direct ascent trajectory involves a very long burn time of 217.4 sec for a third stage that raises considerable problems of thermal protection. The choice is to adopt a coast climb after SECO with a shorter burn of 23 seconds at the apogee.

| Third stage: | | |
|---------------------------------------|------------|-----------|
| Structure & payload, | M_{r3} | =18.75 kg |
| Propellant mass, | M_{p3} | =56.25 kg |
| Payload & equipment, | M_u | =? Kg |
| Third stage mass, | M_{03} | =75 kg |
| Start-up thrust, | T_{03} | =7357.5 N |
| Thrust enhancement, | n_3 | =10.0 |
| Burning time, | t_{b3} | =22.9 s |
| Mass ratio, | μ_{03} | =3.45 |
| Specific impulse, | I_{sp3} | =3500 m/s |
| Ideal velocity 3 rd stage, | W^*_3 | =4852 m/s |
| Global ideal velocity, | W^* | =9102 m/s |
| Real velocity 3 rd stage, | v_3 | =7491 m/s |
| Orbital altitude, | h_0 | =160,0 km |
| Injection downrange, | S_{max} | =650 km |

The start of the three-stage vehicle version begins under a relatively small elevation $\theta_0=64.6^\circ$ that proves a very sensitive parameter for the successful orbital injection. Such ascent trajectories are common for gravity turn ascents, often used for example by the Japanese vehicles of class *Mu*. The coast of the third stage, previously separated from the second stage to enter accurate attitude control, lasts for 135 seconds.

IMPROVEMENTS

The minimal modifications of the propulsion system are shown in Fig. 3 and consist of the following main chapters:

- reinforcement of the inter-stage fixture mount for higher boost thrust;
- clustering of several boosters;
- gimbal mounting of the liquid propellant engine of the second stage;
- transforming the fixed turbine exhaust into a roll control system;
- extending actuators action over the rotating LM;
- stirring fins transform into fixed.

As an alternative, the fins may remain mobile and the position control of the thrust chamber will be achieved in parallel with the basic air fins control from the second stage vehicle. These small improvements pretend a massive computational work of structure verification and suitable high level design technology, to preserve the good reliability of the basic SA-2 vehicle into the present limits or higher. A large series of structure details remain to be also improved, as for example the oxidizer and fuel sinks from the tanks that may be conveniently replaced with direct tank bottom sinks. We recollect that the very mobile sinks are compulsory on board an anti-aircraft rocket vehicle, aimed to perform large maneuvers in following the target airplane, to avoid discontinuities in propellant supply due to the inevitable large amplitude liquid sloshing. The problem of propellant sloshing is critical in all rocket vehicle systems and deserves a special attention. Developments on this subject will be presented in separate papers as one of the main research topics regarding the NERVA orbital launcher. We resume on saying that in most of the current LE space transporter systems a direct aspiration of the propellants from the tank is present. From this simplification some useful mass saving results. Other structural modifications are necessary to improve the stability of the much longer tank section, although a considerable contribution to the structural stiffness is induced by tank pressurization with helium gas, simultaneously used to avoid pump cavitation. They involve stiffening of the out-of-tanks sections of the coke, especially in the lower part of the second stage structure where the dynamic loading is much higher.

A considerable improvement in vehicle ideal velocity is obtained by replacing the

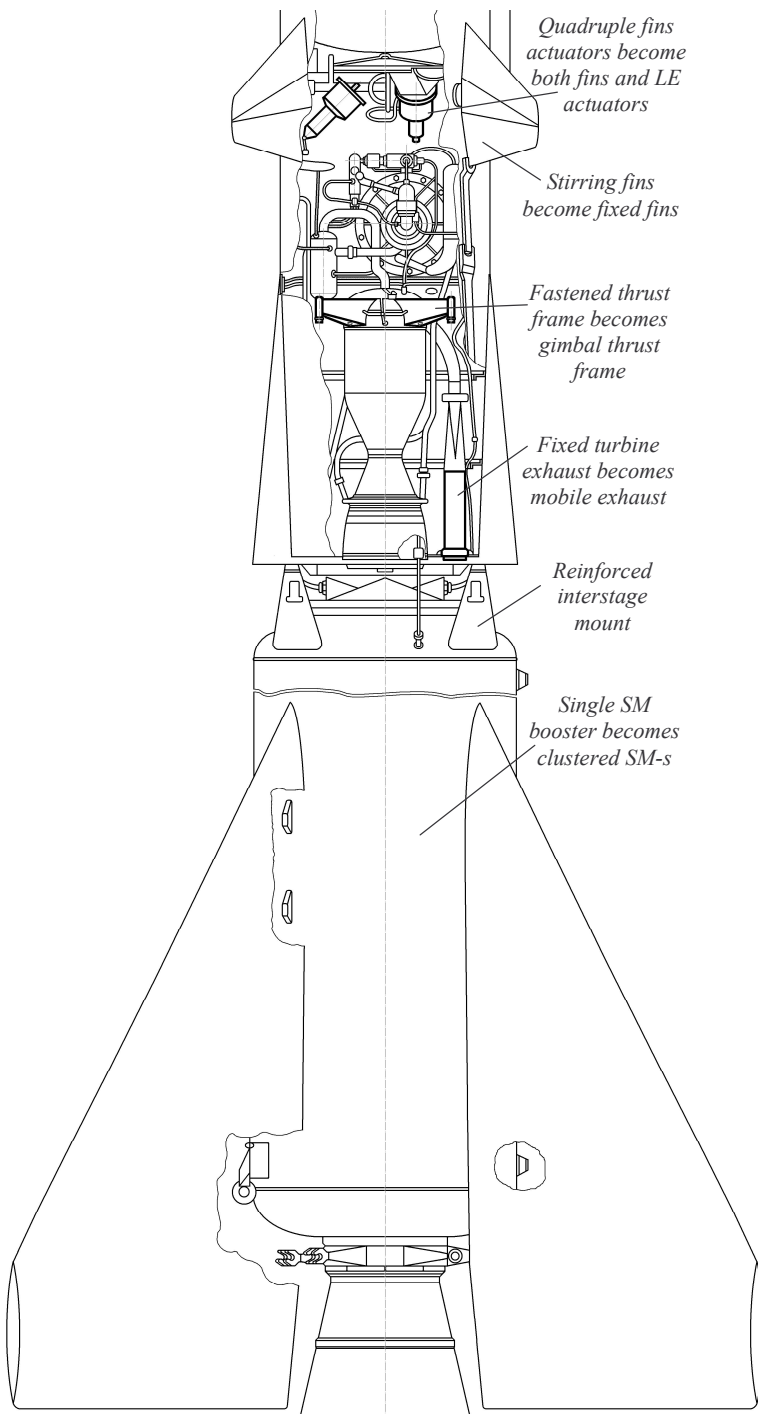


Fig. 3.
Propulsion
enhancements for the
NERVA space launcher.

The third stage must remain under close attitude control during the coast and the powered ascent phases. The drawback of the high thrust-to-weight ratio of the third stage engine is a very high acceleration $a=40g$ at the end of combustion of the third stage.

current propellant A-100 of the first stage booster with the new PEI-400 high energy one, which is expected to raise the sea-level specific impulse from 2200 m/s to almost 2440 m/s¹⁶. The considerable previous experience of the UPB team in developing high energy colloidal propellants is successfully used again.

Otherwise a special emphasis will also be directed towards improvements in the second stage of the vehicle by replacing the standard SA-2 bi-propellant combination with higher energy alternatives. Besides an increased specific impulse of the LRM a reduction of toxicity of the propellant components is targeted, accompanied by a reduction of its impact upon the environment, during the preparation for launch. Cost reductions of the operation will follow.

DEVELOPMENT

The minimal modification of the source vehicle and the design of the minimal PUBSAT satellite involve computational work in all areas, design work in the area of propulsion, structure and avionics and experimental work on laboratory scale and flying versions, all spanned over a period of five years. The preliminary estimates of the development costs of the standard two-staged transporter are at 50 mill. euros level for the five years period.

CONCLUSION

The effect of Earth diurnal rotation will be well exploited whether the launching site is selected on the West Bank of the Black Sea, near the 43.5° northern latitude, at the southern border of the Romanian territory. A convenient 95° (almost East) launch azimuth is considered and the entire length of the Black Sea is thus available for the ascent path, which means a free corridor of 1000 km, with NNW-ESE orientation. Low investments are required for the launch site, due to the specific mobility of the SA-2 Guideline launcher system. The local Earth surface velocity of 328 m/s is added to the vehicle at orbital injection. The lifetime of the LEO satellite will not overpass one month, considered enough to prove the reliability of the NERVA-PUBSAT system and its development potential.

Regarding the second stage LM propulsion system, emphasis will be put in

designing and building a static test facility, presently nonexistent on the Romanian territory, where the propulsive efficiency characteristics of the stage could be definitely monitored. A distinct funding must be provided under a grant contract for this purpose. The main component of the propulsion system supposed to experimental evaluation will be the turbo-pump assembly, electrically driven to securely simulate the working conditions during the powered mission. A test stand should provide the true results of applying new solutions for the turbo-pump.

This turbo-pump test rig will ultimately be used in providing practical information on how the actual turbo-pump will work with different propellant combinations, starting from HTP and nitrogen tetroxide as oxidizers, as alternatives to the present very efficient but hazardous IRFNA (Inhibited Red Fuming Nitric Acid) oxidizer, and up to methanol, nitro-derivatives of methane or even cryogenic liquid methane as liquid fuels. Aluminum powder in a suspension into the fuel will also be investigated. Possible changes in the design of the pumps and of the bearings in particular are expected. Extensive numerical simulations of the combustion process will be performed and will preclude the experimental work, based on the known previous expertise of the team in this field²⁰. Drastic increment in propulsive efficiency and less hazardous manipulation of the propellant components is expected¹⁹. A project proposal for funding of those experimental investigations was recent forwarded and stands under evaluation. A specific contribution of the author to the predicting power of thermochemical computations of the combustion process is related to the observed and still inexplicable cease of chemical equilibrium below a definite temperature of "freezing". A separate, theoretical basic investigation funding request on the causes of such a blocking of chemical reactions at high temperatures in the combustion products of O-N-C-H propellants had successfully passed the first stage of the evaluation process for acceding a national CNCSIS support grant. It will considerably help in providing computational evidence of the efficiency of different propellant combinations here considered for the second stage of NERVA.

Regarding the third stage SM, a balance between requirements and technology must

be further investigated and perhaps a regressive burning geometry and a variable-geometry nozzle would have been introduced. The entire ascent trajectory remains within the inner limits of the region of Black Sea. For a West-East launch from the most southern point of the Romanian territory the orbital plane crosses the Eastern Shore of the Black Sea on the Georgian and Armenian territories. This involves agreements with those countries, otherwise traditional partners of Romania. No special concerns arise, although special political arrangements could prove necessary.

The satellite PUBSAT is envisaged for applications in the field of remote sensing and ground resources surveillance, especially oriented towards enhanced environmental policies. Besides the above mainly envisaged applications, telecommunications in remote areas of the country and home TV networks are also under consideration. The NERVA project enters the class of small, responsive and cheap space transporters, of intense interest. A co-operating activity involving Greece, Spain and US is envisaged. Another recent proposal of co-operation with France for defining the communication system of the PUBSAT satellite is under international evaluation for sponsorship on the European level.

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