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# NERVA VEHICLES, ROMANIA'S ACCESS TO SPACE

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*Colectivul de tehnologie spațială a UPB prezintă paşii imediat abordabili pentru realizarea, în proprietate, a sistemului de lansare cu acces orbital NERVA. Vehiculul NERVA este un mijloc usor disponibil, cu costuri reduse, de demonstrare a posibilității de realizare a zborurilor suborbitale cu o viteză finală la jumătate din viteza orbitală, la altitudine joasă, prin conversia sistemelor sol-aer SA-2 retrase, disponibilizate în România. Se intentioneaza introducerea unui nou si superior sistem de control al atitudinii pe trei axe pentru satelitul minimal PUBSAT.*

*The team for space technology of UPB presents the immediately approachable steps towards the achievement of the proprietary NERVA orbital access launching system. The NERVA vehicle is a readily available and low cost means to demonstrate the feasibility to achieve secured sub-orbital flights with a final velocity of one half the orbital velocity at low altitude by the conversion of retired soil-air SA-2 Guideline systems, obsolete in Romania. A new, superior three-axes attitude control system for the minimal satellite PUBSAT is envisaged.*

**Key words:** orbital vehicles, rocket launchers, space transportation

## 1. 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 cheep space transporters are already raising, only to mention the international [1] "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 failure [6]. It only became operational after four decades with *Pegasus* three-staged launcher, a private system from Orbital [7], with 38 successful missions since 1993.

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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 platform [9].

The involvement of University "Politehnica" of Bucharest (UPB) in FP7 European Space priority projects motivates the development of the *NERVA* launcher [10] 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 industrial partners give confidence in this project [17]. 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 analyzed [10]. The considerations observed are:

- preserve fairly unchanged the basic first stage (booster) construction;
- accept a number of extra boosters to circumvent in a cluster the original one;
- preserve the second stage liquid engine construction fairly unchanged;
- accept a sensible extension in combustion time of the second stage liquid motor;
- allow for a sharp lengthening of propellant tanks of the second stage;
- remove all military equipment and replace it with extra tankage, engine gimbals bearing and a much smaller navigation hardware;
- remove the fixed fins of the second stage;
- direct the action of the stirring actuators from the fins to the liquid motor.

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

## 2. The ascent trajectory and safety aspects

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 $\Delta v$ to the apogee remainder velocity of the carrier vehicle, up to the local circular velocity. The $\Delta v$ 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 $\theta$, the instant distance to the Earth center $r$ and the central angle of view of the path $\varphi$ (Fig. 1). Into a simplified scheme with non-rotating Earth and constant gravitation, the motion always remains in a

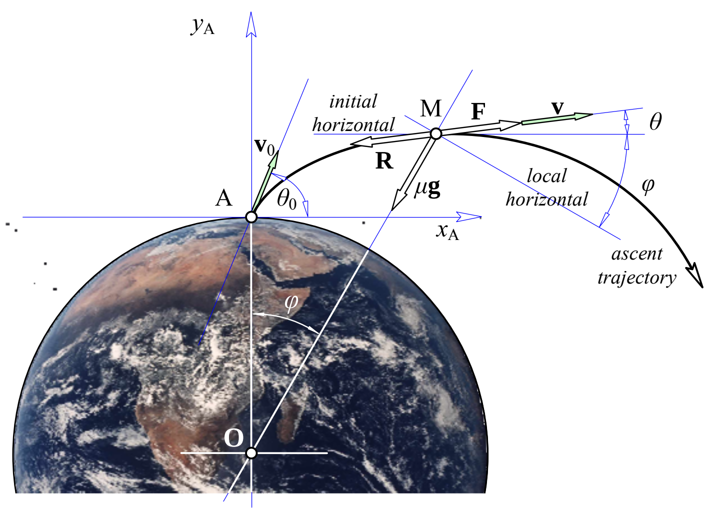

Fig. 1. Geometry of the trans-atmospheric rocket ascent

plane and only depends on three dependent variables [14]. The downrange distance $x_A$ or the equivalent angle $\varphi$ 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

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

These equations are written within the inertial frame $\{Ax_Ay_Az_A\}$, which behaves as bound to the launching site A, with local vertical as for axis $y_A$ and local horizontal $x_A$ directed towards the azimuth direction 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 90º (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, $\mu$ 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 exit [13]), $v_r$ 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,

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

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.

### 3. 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 previously [10]. 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 ($\theta_0$≈86°), 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-of 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. Configuration of basic NERVA is given in Fig. 2 (*a*).

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. Flight profile of basic, inertial guided NERVA, is given in Fig. 2 (*b*).

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. 2 (*b*). 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.

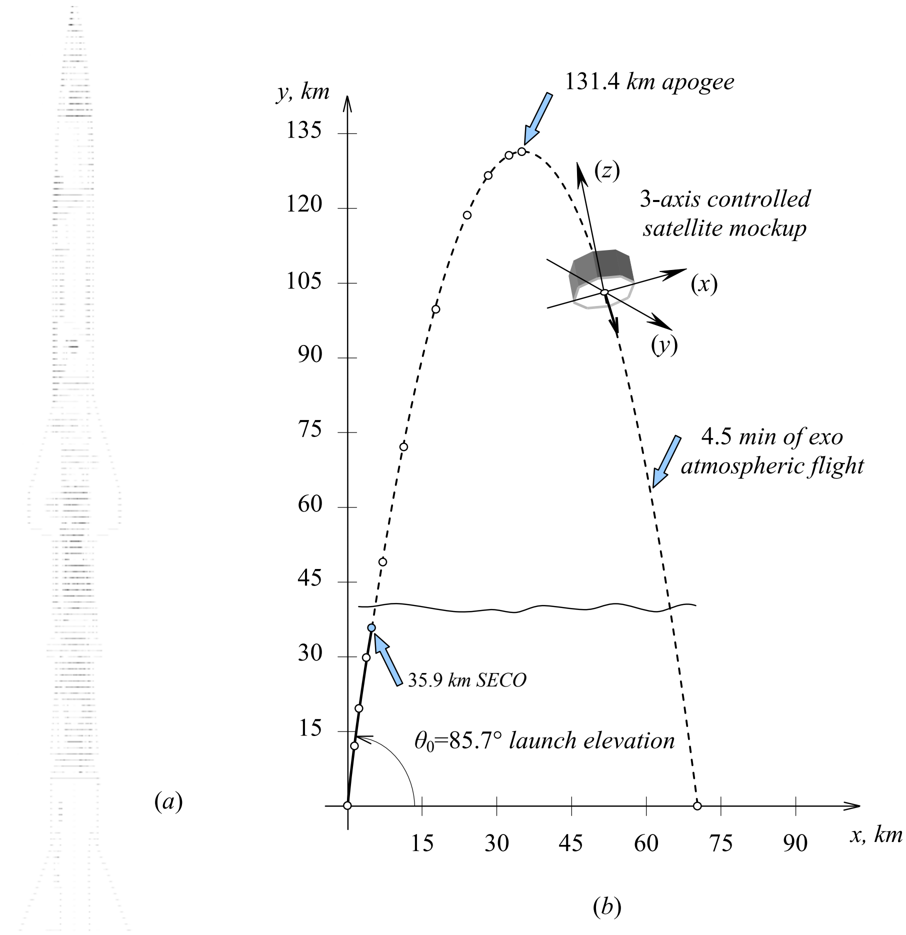


Fig. 2. Basic NERVA (*a*) and flight profile (*b*).

### 4. Performances of NERVA versions

Three two-stage improvements of the standard SA2 rocket were considered, all involving identical, longer second stage, with extended propellant capacity [10], and three or seven first stage SM-s respectively. Each SM delivers 360 *kN* of see-level thrust [11] 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.

*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, | $I^0_{sp1}$= | 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, | $M_u$= | 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, | $I^0_{sp1}$= | 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 |

**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*. 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. Some 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.3. 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 see level specific impulse of 2200 *m/s* at a convenient burn temperature of 2500°*K*. Upgrading is envisaged [16].

## 5. 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 $\theta_0$=54.61º 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. 3.

Fig. 3. V.72.lift-off, artist's concept.

## 6. The third stage for NERVA version V.33

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.

*Table 2*

| Third stage: | | |
|---|---|---|
| Structure & payload, | $M_{f3}$ | =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, | $\mu_{03}$ | =3.45 |
| Specific impulse, | $I_{sp3}$ | =3500 m/s |
| Ideal velocity 3rd stage, | $W^*_3$ | =4852 m/s |
| Global ideal velocity, | $W^*$ | =9102 m/s |
| Real velocity 3rd 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 $\theta_0$=64.6º 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, which had been previously separated from the second stage to enter accurate attitude control, lasts for 135 seconds. The third stage must remain under close attitude control during the coast and all 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.

## 7. Improvements in the propulsion system

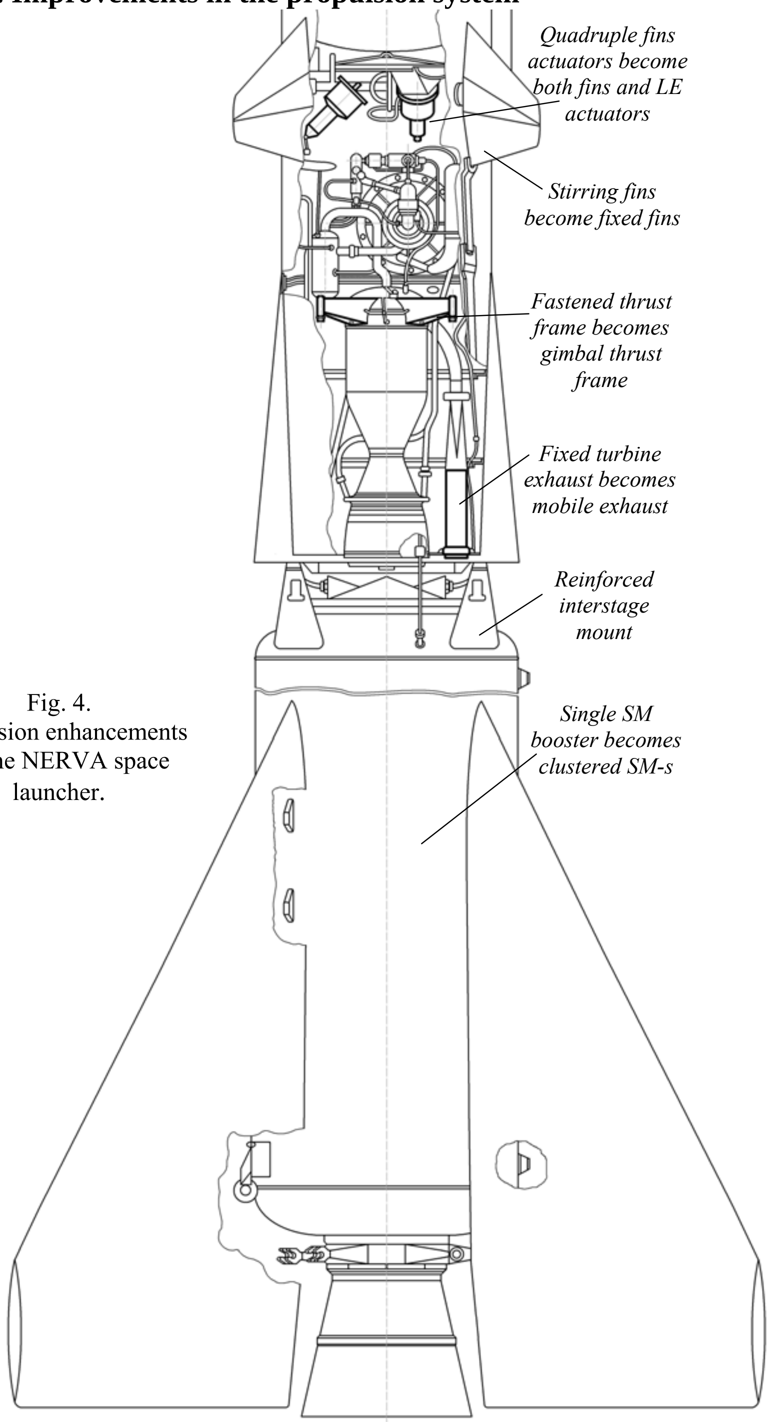


Fig. 4.
Propulsion enhancements for the NERVA space launcher.

The minimal modifications of the propulsion system are shown in Fig. 4 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 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/s [16]. 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.

## 8. Development management of the launcher and satellite

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 tasks of development management are summarized in Fig. 5.

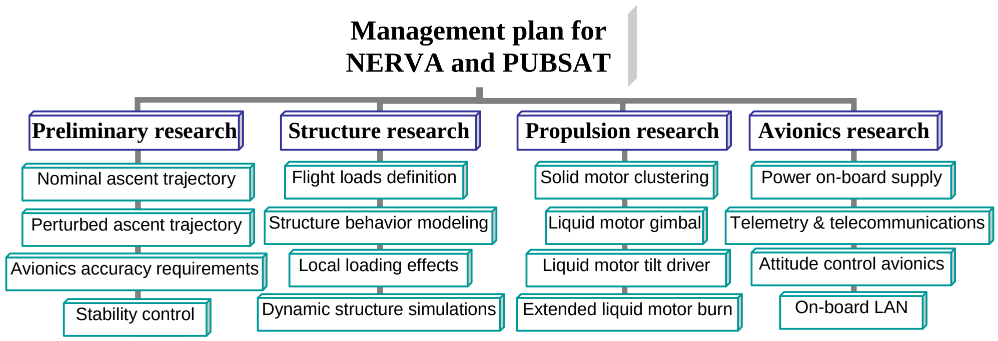

Fig. 5: Management of NERVA and PUBSAT development

The preliminary estimates of the development costs of the standard two-staged transporter are at 50 mill. euros level for the five years period.

## 10. 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 field [20]. Drastic increment in propulsive efficiency and less hazardous manipulation of the propellant components is expected [19]. 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.

# BIBLIOGRAPHY

[1]. *** International Launch Services Press Release, Tuesday, September 6, 2005.
[2]. *** SpaceX Excellent Engineers Wanted, Aviation Week and Space Technology, Sept. 25, 2006, p. 67.
[3]. Sarigul-Klijn, M., Sarigul-Klijn, N., Morgan, B., Tighe, J., Leon, A., Hudson, G. & McKinney, B., Gump, D., Flight Testing of a New Air Launch Method for Safely Launching Personnel and Cargo into LEO, AIAA-2006-1040.
[4]. *** NASA Signes Agreement with t/Space, page last accessed on 02/01/2007 http://www.nasa.gov/home/hqnews/2007/feb/HQ_0720_COTS_agreements.html,.
[5]. *** "Makeyev Offers Site", Aviation Week and Space Technology, 26 April 1993, p. 65.
[6]. Koelle, Heinz Hermann, *Handbook of Astronautical Engineering*, McGraw-Hill, N.Y., 1961.
[7]. Lindberg, Robert E.,Overview of the Pegasus Air-Launched Space Booster, SAE, Aerospace Technology Conference and Exposition, Anaheim, CA, Sept. 25-28, 1989.
[8]. Matsuo, Hiroki; Kohno, Wasahiro; Makino, Takashi; Nagao, Yosuke; Hirose, Hidehiro, Conceptual study of air-launch small satellite launcher system, Space Sciences and Technology Conference, 35th, Nagaoka, Japan, Oct. 28-31, 1991, *Proceedings* (A93-56251 24-12), p.121-122.
[9]. Dr Julian Simon, The Aquarius, a proposal for a nano-satellites launcher vehicle, INTA, Torrej´on de Ardoz, Paper IAC-06-B5.5.05, *Proceedings of the 57th IAC Congress*, Valencia, Spain, Oct. 02-06, 2006.
[10]. Rugescu, R. D., NERVA Romanian Non-Orbital Entry-Return Vehicle Assessor Project, Texas A&M University, USA, Paper IAC-06-B5.5.11, *Proceedings of the 57th IAC Congress*, Valencia, Spain, Oct. 02-06, 2006.
[11]. Steven J. Zaloga, Soviet Air Defence Missiles: Design, Development and Tactics, ISBN 0710605897, Jane's Information Group (November 1989).
[12].***, http://www.flashearth.com/, accessed November 15, 2007.
[13]. Rugescu, R. D., *Teoria zborului aerospațial-optimizarea ascensiunii în atmosferă*, Ed. ManDely, Bucureşti, 2000.
[14]. Rugescu, R. D., Validity Requirements for Base Pressure Measurements on Earth Atmosphere Reentry Bodies for Titan Reentry Applications, *Proceedings of the 4th AAAF International Symposium "Atmospheric Reentry Vehicles and Systems-ARVS"*, March 21-23 2005, Arcachon, France (CD).
[15]. Rugescu, R. D. et al, Contract UPB no. 31-8-11/August 1, 1988 (CCIT of Chemical Works in Fagaras, Romania), *Methodology and Experimental Model for a Telemetry System on Diagrams of Gasdynamic Pressure*, Bucharest, Phase I 1988, Phase II 1989.
[16]. Rugescu, R. D., Al. Codoban, C. Guta, Grant UPB-40-4-5/March 31 1984 (CCIT, Chemical Works in Fagaras, Romania), *Delivery of Maximal Specific Impulse in Engines through the Optimisation of Assimilated Formulations Replacing the Imports*, Bucharest, 1984.
[17]. M. Freeman, Romanian Rocket Research after Oberth, *Executive Intelligence Review*, Vol. 30, No.44, 14 November 2003, New York, USA, p. 25.
[18]. Al. Codoban, *Research on Optimisation of Rocket Flight during the Propellant Burn (Cercetari privind optimizarea zborului rachetelor in timpul arderii combustibilului)*, Teza de Doctorat, UPB Romania, 1978.
[19]. M. *G.* Durschner, Thermochemical Computations on Propellant Powder Gases at Interior Ballistic Pressures and Temperatures, *Propellants and Explosives*, 1 (1976), p.81-85.
[20]. Guta, C., Rugescu, R. D., Contract UPB no. 40-0-3/May 12, 1980 (INCREST Bucharest), *Research regarding performances of rocket engine solid propellants considering condensation* (*number of chemical elements greater than 10*).