

"MARKS" SMALL AVIATION-ROCKET SPACE LAUNCH SYSTEM

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Abstract

The problems of delivery of small space vehicles into low earth orbits are pointed out. The up-to-date means for the ascent of small space vehicles into low earth orbits are analysed. The solution for responsive and economical ascent of small space vehicles into low earth orbits in the form of "MARKS" small aviation-rocket space launch system is offered. Implementation of the offered idea will provide the price of delivery of 1 kg payload into 500 km sun-synchronous orbit equal to 3750 US dollars.

Keywords: Small space vehicle, Low Earth orbit, Space launch vehicle, Aviation-rocket space launch system.

1. Introduction

Owing to reduction of weight, overall dimensions, power consumption and costs of electronic components for space satellites, a number of proposals concerning delivery of small space vehicles (SSV) into low earth orbits (LEO) is promptly increased.

At the same time in the world market of space launch services presented by various rocket space launch vehicles (SLV) and aviation-rocket space launch systems (ARSLS), practically there are no specialized, responsive and economical systems for SSV delivery into LEO.

It is offered to solve the problem of responsive and economical ascent of SSV into LEO by means of creation of "MARKS" small modular ARSLS.

| Nomenclatures | |
|----------------------|--|
| M | Mach number |
| Abbreviations | |
| ARSLS | Aviation-Rocket Space Launch System |
| JSC | Joint Stock Company |
| KhAI | Kharkov Aviation Institute |
| LEO | Low Earth Orbit |
| LPRE | Liquid-Propellant Rocket Engine |
| MSLV | Microsatellite Launch Vehicle |
| PA | Production Association |
| RASCAL | Rapid Access, Small Cargo, Affordable Launch |
| SDO | State Design Office |
| SE | State Enterprise |
| SLV | Space Launch Vehicle |
| SPA | Scientific Production Association |
| SPE | Scientific Production Enterprise |
| SPRE | Solid-Propellant Rocket Engine |
| SSO | Sun-Synchronous Orbit |
| SSV | Small Space Vehicle |
| UAV | Unmanned Air Vehicle |

2. Potential Consumers of Launch Services for Small Space Vehicles

Requirements of potential consumers to launch systems for SSV:

Military services:

- SSV weight: up to 100 kg;
- High responsiveness: time from launch command obtaining prior to flight beginning - no more than 48 h;
- Basic orbits: low circular, basically polar and sun-synchronous (SSO).

Business corporations:

- SSV weight: up to 50 kg;
- Planned character and regularity;
- Basic orbits: various low, basically circular.

Universities:

- SSV weight: up to 10 kg;
- Regularity;
- Basic orbits: various low circular.

Personal consumers:

- SSV weight: up to 1 kg;
- Regularity;
- Basic orbits: various low circular.

3. Existing and Perspective Launch Systems for Small Space Vehicles

In the world market of space launch services presented by various SLV and ARSLS the nomenclature of systems, that provide responsive and economical delivery of SSV into LEO, is extremely limited.

3.1. Operating "Pegasus" ARSLS (Orbital Sciences Corporation, USA) for ascent of space satellites (up to 443 kg) into SSO

Problems:

- High price of one mission for space vehicle launch: about US \$ 56 000 000;
- High price of delivery of 1 kg payload into orbit: about US \$ 126 410;
- Low responsiveness: some months are necessary for mission planning;
- Small regularity of flights: maximum 6 flights in a year (during 1990-2011 period).

3.2. SSV cluster launch by existing SLV ("Dnepr", "Ariane", "Atlas" and some other ones)

Problems:

- Low responsiveness: some years are necessary for planning of space vehicle launch;
- Limited capabilities of orbit type selection (determined by the basic mission of the launcher);
- Small number of flights in a year and low regularity of flights.

3.3. New generation perspective ARSLS for ascent of SSV into LEO (F-15 MSLV, MiG-31 "Ishim", RASCAL projects)

Advantages:

- High responsiveness;
- Capability of ascent of SSV into any desired orbit;
- Low price of mission and delivery of 1 kg payload into LEO.

Problems:

- Projects are not finished or are suspended;
- Practical absence of prospects for projects close-out and new systems implementation.

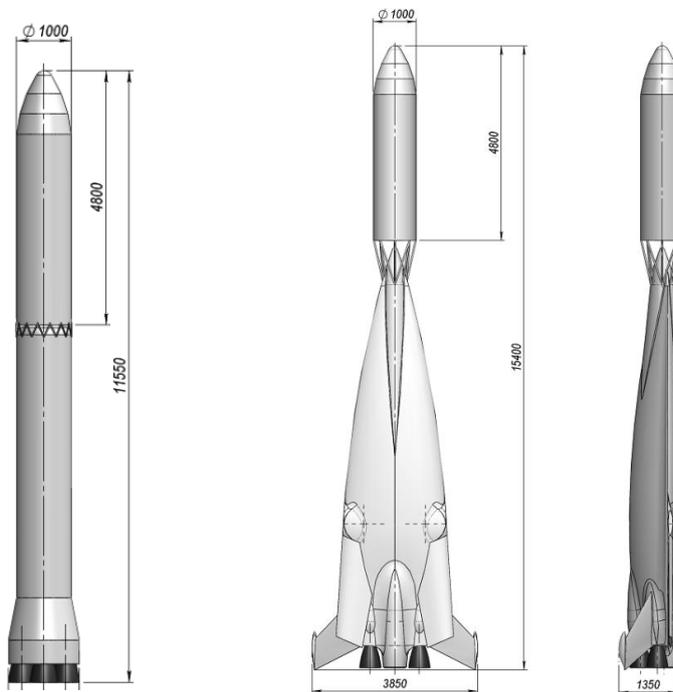
4. The goal of "MARKS" Project and Versions of its Achievement

The project goal is to ensure responsive and economical ascent of SSV into LEO. Engineering proposals concerned two versions of next-generation systems for SSV delivery into LEO were developed for its achievement. General views of two next-generation space launch systems are presented in Fig. 1.

4.1. Base version for achievement of project goal - "Mini-Zenit" small SLV

Technical preconditions for realization of the proposal on the basis of "Yuzhnoye" State Design Office (SDO) backlog [1]:

- Base technical backlog: Well-proven RD-8 liquid-propellant rocket engine (LPRE), using nontoxic propellant components, possessing high specific impulse, high reliability and long life time;
- Improved RD-8M LPRE developmental work is performed: engine thrust is scaled up in comparison with RD-8; engine is configured more compactly; its use as sustainer rocket engine for the first stage of small SLV is admissible;
- Presence of large nomenclature of small combustion chambers for LPRE on which base sustainer rocket engine with necessary thrust can be developed for the second stage of small SLV;
- Presence of backlog for solid-propellant rocket engines (SPRE) on which base sustainer rocket engines with necessary thrust can be developed for upper stages of small SLV (as alternative to LPRE).



(a) "Mini-Zenit" small SLV.

(b) "MARKS" small ARSLs.

Fig. 1. Two versions of next-generation space launch systems.

The basic features of "Mini-Zenit" small SLV:

- Proven technologies and SLV basic components are applied that ensures minimum terms of creation and minimum technical risk of development;

- Low price of SLV launch and delivery of 1 kg payload into LEO;
- Mobility and transportability of space launch complex on the basis of "Mini-Zenit" SLV. The complex can be placed on 3 standard automobile semitrailers (or in 3 standard marine containers);
- High responsiveness: necessary quantity of "Mini-Zenit" space launch complexes can be deployed on suitable ground areas and/or on small marine vessels.

Design and key specifications of "Mini-Zenit" space launch vehicle are presented in Fig. 1(a) and in Table 1.

Table 1. Key specifications of "Mini-Zenit" space launch vehicle.

| | |
|---|-------|
| "Mini-Zenit" SLV launching weight, kg | 5 506 |
| - Oxidizer weight (liquid oxygen), kg | 3 416 |
| - Fuel weight (RG-1 kerosene), kg | 1 331 |
| - SLV structure & space vehicle weight, kg | 759 |
| SLV launching thrust-to-weight ratio | 1.5 |
| SLV first stage: | |
| - Sustainer rocket engine | RD-8M |
| - Weight of charged stage, kg | 4 240 |
| - Weight of stage structure, kg | 481 |
| SLV second stage (version with LPRE): | |
| - Sustainer rocket engine | RD-X |
| - Weight of charged stage, kg | 1 087 |
| - Weight of stage structure, kg | 100 |
| Weight of SLV head part, kg | 179 |
| - Weight of head fairing, kg | 30 |
| - Weight of adapter, kg | 14 |
| - Weight of space vehicle (into 500 km SSO), kg | 90 |

4.2. Alternative version for achievement of project goal - "MARKS" small aviation-rocket space launch system

The basic idea of alternative proposal: as 70...80% of the price of "Mini-Zenit" SLV structure will be made by the price of structure of the first rocket stage with RD-8M LPRE, it is rational to make this stage reusable with aviation landing.

Analogues and prototypes:

- Reusable accelerating module "A" with aviation landing from perspective family of "Uragan-GK-175" space launcher (successor of "Energia-Buran" system, USSR) [2];
- Reusable universal accelerating module "Baikal" with aviation landing from perspective family of "Angara" space launcher, Russian Federation [3].

Technical preconditions for realization of the proposal regarding "MARKS" small ARSLS in Ukraine:

- Results of the possible detailed developmental work of "Mini-Zenit" small SLV;
- Experience and technical base of "NII PFM KhAI" research institute in the field of creation and tests of pilotless (remotely-piloted) large-scale

dynamically-similar models with take-off weight up to 1,200 kg of perspective airplanes of P.O. Sukhoi, A.I. Mikoyan and V.M. Myasishchev experimental design offices;

- "Yuzhnoye" SDO and "NII PFM KhAI" research institute joint experience in conceptual project development of components of "TKS" space transportation system on the basis of high-altitude (up to 30 km) and high-speed (> 4 M) unmanned air vehicle (UAV). Procedures are developed for justification of UAV configuration, calculation of its aerodynamic characteristics up to 6 M speed, mathematical modelling of UAV flight trajectories, etc. The configuration of "KUS" navigation, control and radio communication complex of "TKS" UAV is justified. The stage-by-stage plan of experimental optimization of "TKS" UAV and "KUS" complex is offered using technical base of "Yuzhnoye" SDO, "KhAI" university, "NII PFM KhAI" research institute, "Khartron" joint stock company (JSC) and other enterprises and organizations in Ukraine;
- Scientific potential of leading high schools in Ukraine (KhAI, KPI, DGU and others), industrial groundwork of aviation and space-rocket branch enterprises in Ukraine ("Yuzhnoye" SDO, PA "Yuzhmash" state enterprise, SPA "PKhZ" SE, SPE "Dneprotekhservice", "Antonov" SE, "Motor Sich" JSC, Kharkov Machine-Building Plant "FED" SE, Kharkov State Aircraft Manufacturing Company, "Khartron" JSC, "Polysvit" special design office and others.

The basic features of "MARKS" ARSLS (as well as for "Mini-Zenit" small SLV):

- Proven technologies and basic components are applied that ensures minimum terms of creation and minimum technical risk of development;
- Low price of ARSLS launch and delivery of 1 kg payload into LEO;
- Mobility and transportability of space launch complex on the basis of "MARKS" ARSLS. The complex can be placed on 3 standard automobile semitrailers (or in 3 standard marine containers);
- High responsiveness: necessary quantity of "MARKS" space launch complexes can be deployed on suitable ground areas and/or on small marine vessels.

Additionally to features of "Mini-Zenit" small SLV, "MARKS" ARSLS has following advantages:

- Reusable first stage on the basis of RD-8MM LPRE ensures reduction of price of ARSLS launch and SSV delivery into orbit. In addition, special organization of safety measures in areas of prospective falling of SLV first stage is not required;
- Conventional aviation landing of "MARB" reusable universal aviation-rocket accelerating module onto 500 m landing strip or on water surface (in case of need) is implemented;
- "MARB" reusable accelerating module has reserves of weight and volume for placement of auxiliary air-breathing jet engine (Motor Sich MS-100 turbojet, for example) for increase of range from ARSLS upper rocket stage launch point to "MARB" module landing area.

Design and key specifications of basic version of "MARKS" space launch system are presented in Figs. 1(b), 2, 3 and in Table 2.

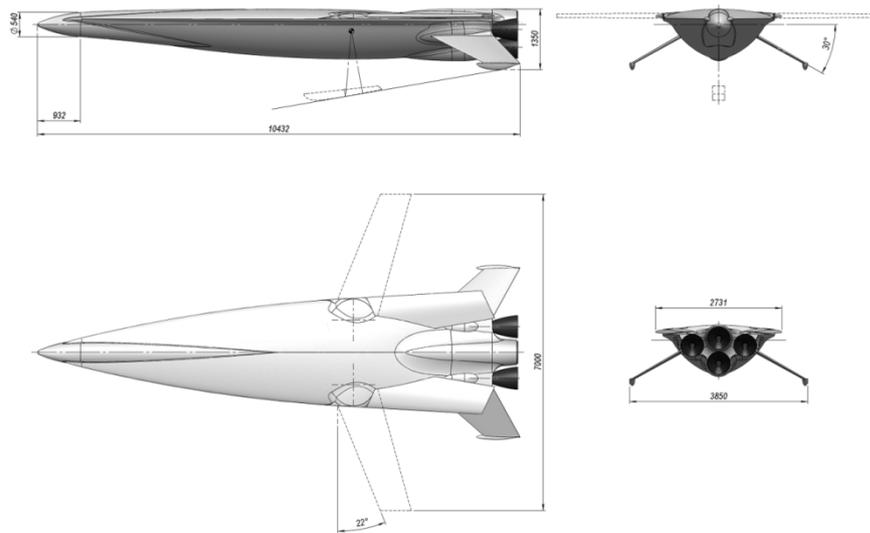
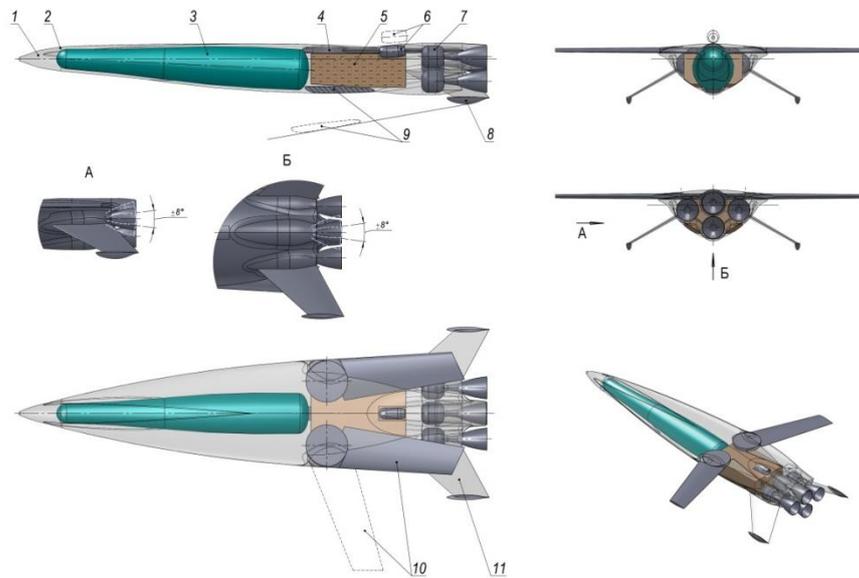


Fig. 2. "MARB" reusable universal aviation-rocket accelerating module: general view and basic sizes.



1 - accelerating module airframe; 2 - load-bearing bulkhead; 3 - oxidizer tank (liquid oxygen, 2 390 l); 4 - outer wing pivot assembly; 5 - fuel compartment (kerosene, 1 800 l); 6 - MS-100 turbojet; 7 - RD-8MM LPRE; 8 - tail landing support; 9 - main landing ski; 10 - pivoted outer wing; 11 - tail fin panel

Fig. 3. "MARB" reusable universal aviation-rocket accelerating module: layout diagram.

Table 2. Key specifications of "MARKS" space launch system.

| | |
|---|--------|
| "MARKS" ARSLS launching weight, kg | 5 611 |
| - Oxidizer weight (liquid oxygen), kg | 3 416 |
| - Fuel weight (RG-1 kerosene), kg | 1 331 |
| - SLS structure & space vehicle weight, kg | 864 |
| ARSLS launching thrust-to-weight ratio | 1.47 |
| ARSLS first stage - "MARB" reusable accelerating module: | |
| - Sustainer rocket engine | RD-8MM |
| - Weight of charged stage, kg | 4 360 |
| - Weight of stage structure, kg | 601 |
| ARSLS second stage (version with LPRE): | |
| - Sustainer rocket engine | RD-X |
| - Weight of charged stage, kg | 1 087 |
| - Weight of stage structure, kg | 100 |
| Weight of ARSLS head part, kg | 163 |
| - Weight of head fairing, kg | 29 |
| - Weight of adapter, kg | 12 |
| - Weight of space vehicle (into 500 km SSO), kg | 80 |

Design versions of the upper rocket modules for "MARKS" small ARSLS:

- Single-stage rocket module on the basis of perspective small thrust LPRE designed by "Yuzhnoye" SDO, equipped with jet propulsion roll control system;
- Two-stage rocket module on the basis of perspective SPRE designed by "Yuzhnoye" SDO, equipped with jet propulsion roll control system;
- Two-stage rocket module designed by "Yuzhnoye" SDO on the basis of "STARTM" SPRE series produced by ATK Company (USA), equipped with jet propulsion roll control system.

5. Economic Aspects of "MARKS" System

Some technical and economic aspects of "MARKS" system are presented in Tables 3, 4 and 5.

Table 3. Base data for calculation of economic parameters of "MARKS" space launch system.

| | RASCAL system [4] | "MARKS" system |
|--|-----------------------------------|----------------------------------|
| Weight of reusable aircraft stage structure, kg | 20 496 | 601 |
| The price of reusable aircraft stage structure, US \$ | 446 000 000 (the first sample) | 13 074 690 (the first sample) |
| Fuel required for one flight, kg: | | |
| Liquid oxygen | 270 | 3 416 |
| Kerosene | 10 061 | 1 331 |
| The price of 1 kg of fuel, US \$ | | |
| Liquid oxygen | 0.52 | 0.52 |
| Kerosene | 1.00 | 1.00 |

Table 4. Preliminary price parameters of "MARKS" system.

| The price of one launch, US \$ (share of reusable aircraft stage) | | |
|--|--------------------------|-----------------------|
| Reusable aircraft stage number of flights: | RASCAL system [4] | "MARKS" system |
| 100 | 4 470 201 | 133 854 |
| 1000 | 456 201 | 16 185 |

| The price of delivery of 1 kg payload into 500 km SSO, US \$ (share of reusable aircraft stage) | | |
|--|--------------------------|-----------------------|
| Reusable aircraft stage number of flights: | RASCAL system [4] | "MARKS" system |
| 100 | 40 638 | 1 673 |
| 1000 | 4 147 | 202 |

Table 5. Comparison of technical characteristics and economic parameters of some ARSLs with reusable aircraft stages.

| | "Pegasus" [5] | RASCAL [4] | F-15 MSLV [6] | "MARKS" [7] |
|---|----------------------|-------------------|----------------------|--------------------|
| System launching weight, kg | 200 000 | 38 351 | 30 800 | 5 611 |
| Weight of upper rocket stage with space vehicle, kg | 23 130 | 6 474 | 4 550 | 1 250 |
| Upper rocket stage start point: | | | | |
| - Altitude, km; | 12.8 | 67 | 11.5 | 70 |
| - Mach number | 0.82 | 2.97 | 2.0 | 6.0 |
| Space vehicle weight (into 500 km SSO), kg | 443 | 110 | 73 | 80 |
| System weight effectiveness, % | 0.220 | 0.287 | 0.237 | 1.426 |
| The approximate price of one launch of system, US \$ | 56 000 000 | 6 000 000 | 5 000 000 | 300 000 |
| The price of delivery of 1 kg payload into 500 km SSO, US \$ | 126 410 | 54 500 | 68 500 | 3 750 (initial) |

6. Conclusions

The description of the problems existing in the world market of space services connected with the ascent of small space vehicles (SSV) into low earth orbits (LEO) is stated. Existing and prospective means for the ascent of SSV into LEO are analysed.

The proposal concerning solution of the problems of responsive and economical ascent of SSV into LEO in the form of "MARKS" small modular aviation-rocket space launch system is justified.

Efficient realization of the presented proposal on the basis of existing groundwork of enterprises and organizations of domestic aviation and space-rocket branch will allow Ukraine to take profitable position in the escalating market of space launch services.

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