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Exploring the Possibilities for Improving the Performance of the Adapters used for Launching Multiple Small Space Vehicles on a Single Launch Vehicle

Viktor Nikolaevich Blinov*, Viktor Vladimirovich Shalay and Igor Sergeevich Vavilov

Omsk State Technical University, Omsk, Russian Federation;
va_va-igg@mail.ru, monblan.pro@yandex.ru

Abstract

Background/Objectives: The research is aimed at determining the ways to improve the effectiveness of reconfigurable and extendable multipurpose adapters for multiple launch of small space vehicles by a launch vehicle. **Methods:** The structural design method is selected for studying design and constructive shape of the SSV adapters. The structural approach was used to define the principle for optimization of adapters of various constructive schemes, excluding modifications of launch vehicle used for multiple launches and enabling to extend and reduce adapter configuration with respect to a universal basic structure used for all tasks for SSV launch to be solved. **Findings:** To obtain quasi-optimal design and engineering parameters for the entire target set of tasks solved by the adapter, based on the structural approach we have considered design schemes of multi-purpose adapters for multiple and concurrent launching of SSVs of rod, shell, beam and platform types with side and end attachment configuration, the schemes with shock absorbers mounted in the places of adapters and MCAs installation, and scheme configuration combining adapter + small upper stage. The base and extension structures have been determined to form multi-purpose adapter with flexible and extensible design. As a result of the proposed technical solutions, weight of the adapter is reduced by 30%, configuration density is increased by 30-40 %, the number of the launched SSVs is increased, the fairing length and weight is reduced by 50%, root-mean-square amplitudes of accidental vibration decreased by 2.5-3 times, level of shock loads during SSV separation decreases by 6-10 dB, provision is made for shockless separation of SSV required lateral alignment of LV, cost reduction for ground and flight tests. **Application/Improvements:** Further improvement of the multi-purpose adapters is connected with the co-design of “Adapter + SSV” system, taking into account the mutual influence of design and engineering parameters of the SSV, adapter and LV used to launch them.

Keywords: Adaptation, Adapter, Launch Vehicle, Launching Multiple SSVs on Single LV, Payload Fairing, Payload Area, Small Space Vehicle, Separation System, Turntable

1. Introduction

Today, space engineers are mostly focused on developing SSVs for solving a wide range of scientific, practical and educational problems.[1-5]

Further development of a great variety of functionally and structurally complicated SSVs put forward the task of launching multiple SSVs on a single launch vehicle using adapters (dispensers) in the form of special power structures installed on launch vehicles (LV).[6]

While developing such adapters, it should be borne in mind that their design and engineering parameters shall be compatible with those of SSV and LV. For instance, SSVs are placed into their target orbits being powered either by LV upper-stage motors or SSV micromotors.[6-8] Mechanical vibration during SSV insertion into orbit is

*Author for correspondence

reduced either by selecting appropriate LV (if possible), or incorporating shock absorbers into the adapters[6].

A growing trend towards the development of SSV-based space systems, as well as a gradual increase in several payloads launched from a single launch vehicle make it even more important to improve the performance of the adapters used for deploying SSVs on different orbits with one launch, including using a multipurpose approach.[9,10]

The weight of the adapter is a key parameter used to measure its performance. Therefore, weight reduction is crucial for increasing the overall efficiency of the adapter. The weight of the adapter depends on the number and weight of SSVs installed on the adapter, SSV mounting methods (with or without turntables), LV loads, as well as the SSV installation site and may vary from 14% to 45% of the weight of SSVs to be launched.[6]

When designing the adapters, the main task is to preserve their operating and technical characteristics required for SSV launch and solve the task of launching more than one SSV aboard single LV by developing new highly efficient designs for the adapters.

2. Literature Review

The main requirements to the adapter predetermining its design include:

- high density of SSV packaging;
- SSV shockless separation;
- the longitudinal and lateral centers of gravity of the Adapter + SSV system shall fall within specified limits to ensure LV stability and controllability during the SSV insertion into orbit;
- reduced shock and vibration generated by LV with increased operational loads for SSV as part of the adapter;
- lowest possible weight of the adapter;
- separation and delivery of SSVs into their target orbits.

Today, a guaranteed result method is used to develop multipurpose adapters for single launchers placing multiple SSVs on orbit. It stipulates creating an invariable adapter design making the adapter well suited for launching maximum SSVs on single LV. If the maximum number of SSVs is chosen to be less than the number of SSVs that can potentially be mounted on a particular adapter, a multipurpose adapter turns out to be parameter and structurally redundant depending on the size and weight of SSVs [6,9,10].

A good example of the multipurpose adapter is an Arianespace structure called ASAP (Ariane Structure for Auxiliary Payload) installed between the third stage of LV and the primary space vehicle (SV) carried by LV[6]. Similar technology is applied by Kosmotras, a commercial operator of the Dnepr Space Launch System. SSVs are mounted on the ASAP-type adapter installed on the booster stage of LV[6].

The packaging density of the Adapter + SSV system can be increased by selecting an appropriate adapter design and layout and SSV geometry, as well as an appropriate installation site for SSV (adapter end or side). A required number of SSVs with specific size and weight is mounted on the adapter taking into account the payload area within the LV fairing and the LV power constraints.

The best results can be achieved by codesigning the adapter and SSV to make them well suited for specific LV.

Thus, for more efficient utilization of the carrying capacity of Delta 2 LV, Globalstar SV was made in the shape of a quadrangular trapezoidal prism, which enabled launching of four Globalstars aboard single Delta 2. Yet, for Globalstarts transportation into orbit on Soyuz-U, a two-tier installation configuration was used, with SSVs mounted on the side surface of the adapter (Figure 2)[6].

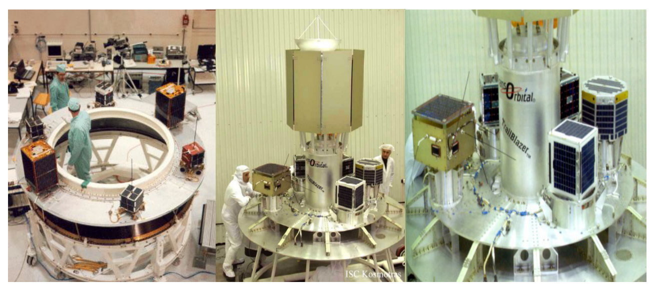


Figure 1. ASAP (a) and ASAP-type (b) Adapters Used for SSV Launch.

Figure 2. Ikar Upper Stage with four Clobalstars.

The increased density of SSV packaging on LV is ensured as follows:

- SSVs may be mounted on both the end and side of the adapter, while solar panels are positioned on SSVs in such a way as to ensure maximum SSV packaging density (Figure 3)[6,11];
- the core equipment and the auxiliary equipment with the motor assembly and the adapter attachments are made as separate modules connected to each other parallel to the LV flight path[6,12].

Such scheme provides a more stable geometry of the auxiliary equipment with the adapter attachments having a positive effect on the overall codesigning process (Figure4).

SSV installation on the adapter side ensures SSV shockless separation. Figure 5 (a,b) shows two GRACE SVs installed on the side of MSD (Multi-Satellite Dispenser) in the form of a rectangular cross section column during the Rokot LV launch (a); Champ and Mita SSVs and the Bird-Rubin communications payload mounted on the truss adapter of Kosmos-3M LV[6].

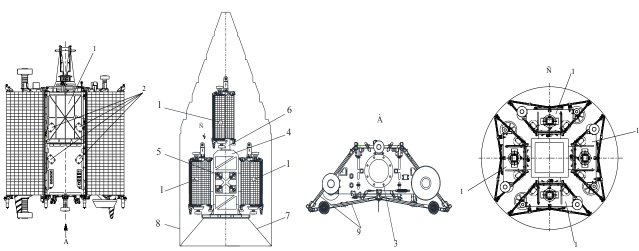


Figure 3. End and Side Installation of Identical SSVs on the Adapter Ensuring High Packaging Density 1 – SSV; 2 – side separation system attachments; 3 - end separation system attachments; 4 – adapter; 5 – side separation system; 6 – end separation system; 7 – LV; 8 – payload area within LV; 9 – solar panels.

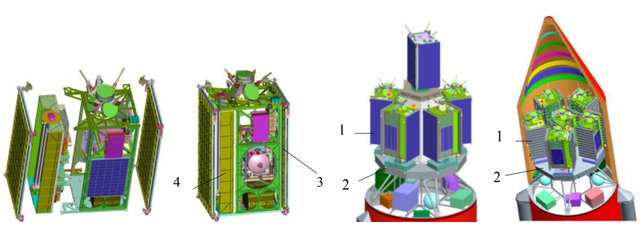


Figure 4 SSV with Parallel Core and Auxiliary Equipment Modules Installed on the Adapter End 1 – SSV; 2 – adapter; 3,4 – core and auxiliary equipment modules.

Figure 5 (c) shows NEXTSat, ASTRO, STPSat-1, CFESat, MidSTAR-1 and FalconSat-3 (54 kg) installed on cylindrical ESPA (EELV Secondary Payload Adapter)[6].

The adapters for the end installation of SSVs used for Kosmos-3M and Soyuz-ST-A LVs are shown in Figures 6 and 7. SSV shockless separation is ensured by the adapter turntables[6,14,15].

There are also adapters designed for launching primary SV and secondary SSVs on a single launch vehicle and mounted on the LV compartments used for the retention of primary SV[6,16]. While adapting such SSVs, the main task is to ensure minimum modifications of the LV compartments.

The adaptation of Japan's primary SV (Ibuki) and seven secondary SSVs (SSV SDS-1, Sprite-Sat, SOHLA-1 (Maido-1), Sorunsat-1 (Kagayaki), KKS-1 (Kiseki), STARS-1 (Kukai) and PRISM (Hitomi)) to H-IIA LV includes mounting of primary SV and secondary SSVs on the special adapters installed on the LV compartment (Figure 8a). Similar approach is used for the adaptation of primary SV and secondary SSVs to Kosmos-3M LV (Figure 8)[6,16].

Increased efficiency of a single launcher placing several SSVs on orbit is achieved by using small upper stages (SUS) or third stages of LV as part of the adapters for SSV separation and insertion into desired orbits[6,18].

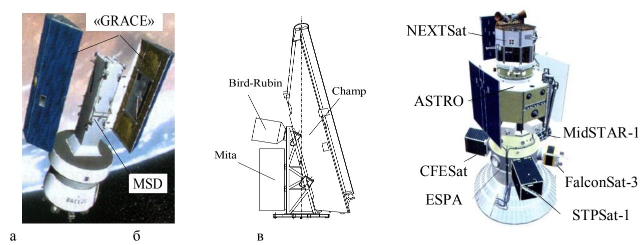


Figure 5. Side (a, b) and Combined (c) Installation of SSVs on the Adapter .

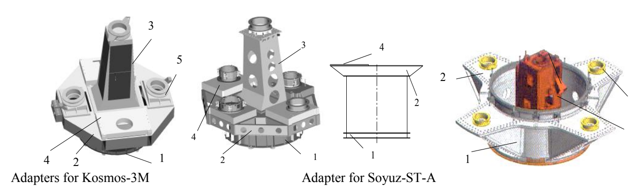


Figure 6. Adapters for SSV End Installation 1 – LV attachments; 2 – SSV installation platform; 3 – upper SSV compartment; 4 – turntable; 5 – SSV support bracket (with or without a separation system); 6 – SSV inside the adapter.

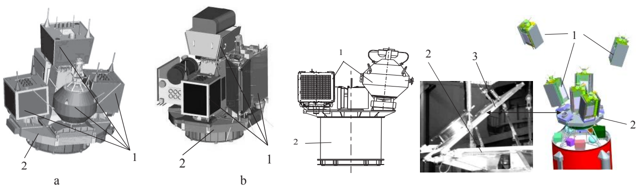
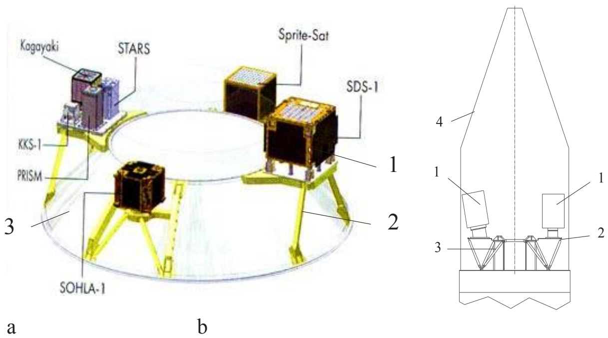
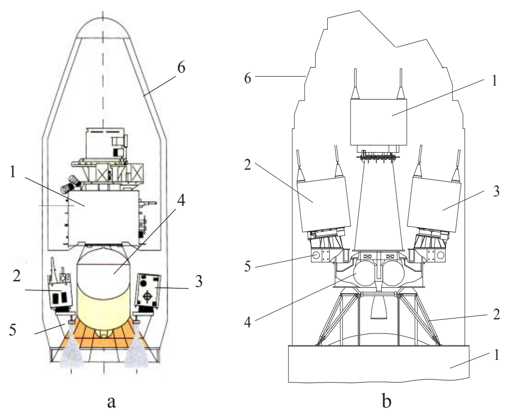


Figure 7. End Installation of SSVs on the Adapters (a) and Separation of SSVs Using Turntables (b) 1 – SSVs to be separated; 2 – adapter; 3 – turntable.



a – adaptation to H-IIA; b – adaptation to Kosmos-3M

Figure 8. SSV Installation on the LV Compartments (Frames) 1 – SSV; 2 – adapter for the installation of secondary SSVs; 3 – LV compartment (frame) for the installation of primary SV; 4 – payload area within LV.



a – design and layout; b – base structure of the adapter

Figure 9. Integration of the Adapter with the LV Upper Stage 1, 2, 3 – SSV; 4 – LV upper stage; 5 – adapter; 6 – payload area.

Series connection of the adapter and SUS would increase the overall length of the structure thus reducing the payload area within the LV fairing. An optimum solution would be SUS integration with the adapter ensuring high density of the payload packaging within the LV fairing (Figure 9)[18].

While adapting India's Resourcesat-2 and YouthSat and Singapore's X-Sat to PSLV-C16 LV, the adapter was integrated with the LV upper stage (Figure 9a). The SSV installation configuration shown in Figure 9b is used for LVs of Kosmos-3M type providing for the incorporation of the upper-stage motor into the LV compartment.

3. Research Methods and Materials

With a wide variety of SSV designs, there is a multi-objective task of further developing SSVs and their components, as well as devices for SSV adaptation to LV if several payloads are going to be launched from a single launch vehicle[7-12].

Today, a guaranteed result method is used to develop multipurpose adapters. The parameters shall ensure the most complex objective to be met.[9,10]

When setting design P_j and structural S_j parameters according to the guaranteed result method, the efficiency of the multipurpose adapter is different for different target objectives. For the adapter with fixed parameter vectors P_j and S_j, the highest efficiency is achieved for objective o^* among all target objectives $d(o)$: $o^* \in d(o)$. Yet, for other objectives $o \in d(o)$, lower local efficiency is observed compared to maximum efficiency values $J(o^*, p, s)$[10].

A more effective method for choosing optimal adapter parameters would be a structural design method ensuring near-optimal solutions for all target objectives (quasioptimal solutions) by restructuring the adapter for solving specific tasks.

To formalize the study of the adapter structural parameters, the adapter structural design can be represented as:

$$S^*: S_B \times S_K \quad (1)$$

where S^* - a set of values of design parameter vector s determining the structural design of the adapter;

S_B – a set of values of vector s_B determining the base structure of the multipurpose adapter used for meeting the full range of target objectives;

S_E - a set of values of vector s_E determining the extension structures of the multipurpose adapter used for meeting particular target objectives.

The base structure of the adapter shall ensure minimum modifications of LV used for SSV launch and lowest possible weight of the adapter.

The extension structures along with the base structure shall ensure the adapter main task of launching payloads into orbit to be performed in a quasioptimal way, while simultaneously meeting the adapter requirements discussed below:

- the lateral center of gravity of the Adapter + SSV system shall fall within specified limits to ensure LV stability and controllability during the deployment of SSVs installed on the side of the adapter;
- reduced shock and vibration of SSV as part of the adapter;
- shockless separation of SSVs mounted on the end of the adapter with the help of the adapter turntables;
- minimum modifications of the LV compartment used for the installation of primary and secondary SSVs with preserving the overall stiffness of the structure and the payload capacity of LV;
- lowest possible weight of the adapter.

The multipurpose structural approach generates a great variety of high performance adapters used for launching several payloads from a single launch vehicle.

4. Results

The multipurpose structural approach can be used for developing different adapter designs.

For example, for SSVs with different weight mounted on the side of the adapter, the adapters in the form of a truss with the LV attachment ring are used, with the side mounting surfaces of the truss being positioned perpendicular to and at angle β to the LV attachment plane[6,13]. With the structural approach, the LV attachment ring is a base structure, whereas the truss is an extension structure.

Angle β of the mounting surface for SSV 1, if properly chosen, ensures the lateral center of gravity of the Adapter + SSV system.

Thus, for SSVs 1-3, with a weight of 500 kg, 180 kg and 50 kg, respectively, the moment about the lateral axis is 132 kg·m. It is compensated for at angle β ≈ 77° (Figure 10).

Depending on the adapter, there may be various designs of the base structures attached to LVs (Figure 11).

Base structures ensure:

- mechanical and electrical interfaces with LV;
- reduced SSV shock and vibration.

The second problem can be solved by incorporating shock absorbers into the LV attachment rings[15]. It becomes critical as the need arises for adapting already existing SSVs to LV with higher operational loads placing multiple SSVs into their orbits. Shock absorbers may also be mounted at the SSV installation sites (Figures 12, 13).

Compared with rod and shell adapters with no shock absorbers, adapters with shock absorbers reduce accidental vibration affecting SSV, root-mean-square amplitudes of accidental vibration, as well as SSV shock loads during SSV separation (Figure 14)[15]:

The shockless separation of SSVs mounted at the end of adapter platform is ensured by turntables being, along with the platforms, the extension structures of the multipurpose adapter (Figure 7). The turn of the turntable with SSV by a safe angle allows for higher density of the payload packaging within the LV fairing, as well as shockless separation of SSVs.

When developing turntables, it is important to reduce the costs required for their ground and flight tests[14].

Let us take the case of a SSV constellation to be built by launching multiple LVs each carrying more than one SSV into orbit. The first step in the process is to manufacture and launch demonstration SSV mounted on the adapter with an in-built turntable.

To cut down on the costs needed for further development of the turntable, it undergoes ground and flight testing as part of the flight adapter before and during the SSV demonstration flight (Figure 15)[14].

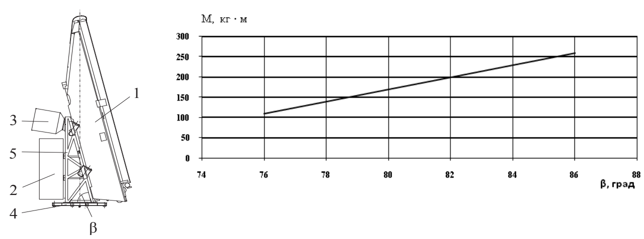


Figure 10. Dependence of Mass Moment on the Angle of the Mounting Surface of the Adapter with SSVs 1-3 to the LV Attachment Plane 1, 2, 3 – SSVs; 4 – LV attachment ring (base structure); 5 – SSV truss frame (extension structure).

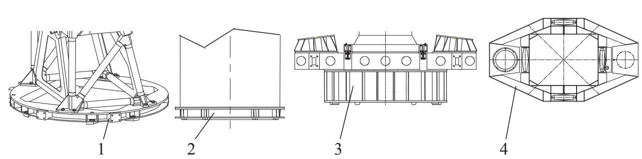


Figure 11. Base Structures Attached to LVs 1,2 – rings; 3 – compartment; 4 – platform

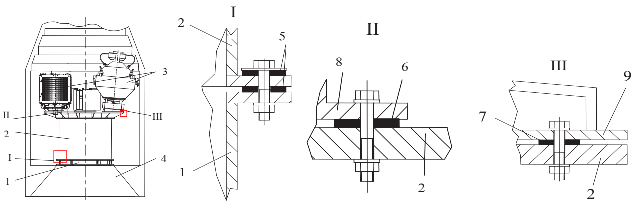


Figure 12. Shock Absorbers Installed in the Cylindrical Adapter Joints 1 – LV attachment ring; 2 – adapter casing; 3 – SSV; 4 - LV; 5,6,7 – rubber shock absorbers incorporated into the LV attachment rings or mounted at the SSV installation sites; 8,9 – SSV attachments.

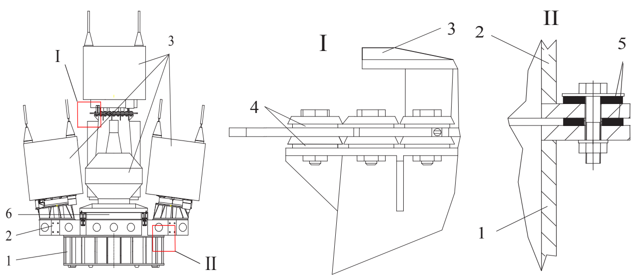


Figure 13. Shock Absorbers Mounted in the Adapter Joints 1 – LV attachment ring; 2 – adapter platform; 3 – SSV; 4,5 – rubber shock absorbers; 6 – turntable.

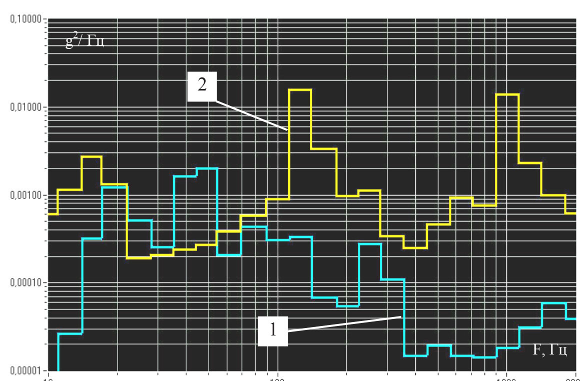


Figure 14. Results of the Adapter Tests for Accidental Vibration 1 – adapter with shock absorbers; 2 – adapter with no shock absorbers.

The turntable flight tests are carried out during the launches of demonstration SSVs as secondary payloads on the turntables being part of the adapters that have undergone the ground tests. At least a threefold margin of safety shall be ensured for the adapter during the tests.

The separation of demonstration SSV from the turntable is performed with the turntable fixed in its initial position. Thus, the standard separation takes place with

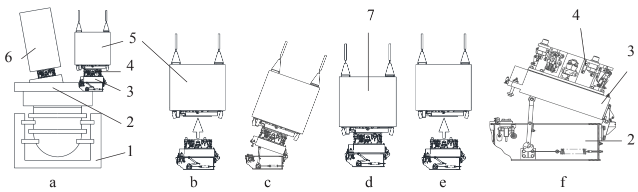


Figure 15. Ground and Flight Test Sequence for the Adapter Turntable a – tests on the adapter with SSV mockups; b – SSV separation system tests; c – turntable tests; d – adapter with the turntable, the separation system and SSV in flight configuration; e – SSV separation; f – turn of the adapter turntable. 1 – vibration bench; 2 – adapter; 3 – turntable; 4 – separation system; 5, 6 – mockups of demonstration and primary SSVs; 7 - SSV

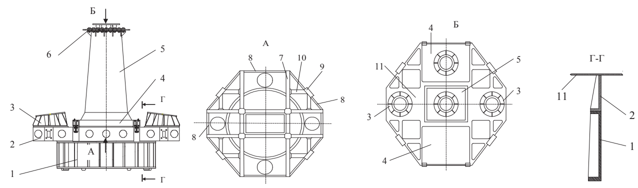


Figure 16. Structural Layout of Platform-type Adapter Having Minimum Weight 1 – LV attachment ring; 2 – adapter platform; 3 – SSV support bracket; 4 – turntable; 5 – upper SSV tier installation rack; 6 – damping unit; 7,8,10 – primary, secondary and supporting beams; 9 – hoist fittings; 11 – plate

the turntable having no impact on the SSV separation process.

Maximum loads are acting on the turntable during the SSV launch and deployment. Therefore, it is important to check whether the turntable has turned or not after the exposure to maximum flight mechanical loads. For this purpose, the turntable is turned and the corresponding measurements are communicated through the LV telemetry system after the SSV is separated from the turntable.

The above method for testing the adapter turntable allows for a significant time and cost reduction due to the reduction in the facilities and equipment required for the tests, as well as the flight testing of the turntable as part of SSV launched as a secondary payload[14].

The adapter platform being the adapter extension structure used for SSV installation with or without turntables has significant size and weight.

Experience shows that the problem of ensuring minimum size and weight of the adapter platform becomes critical if multiple SSVs (4-6) with a weight of 120 kg and more are launched on single LV. If four to five SSVs are going to be deployed at once by single LV, the weight of the platform far exceeds the weight of the LV attachment ring. For instance, for the adapter designed for five SSVs with a total weight of 550 kg, the weight of the platform with the SSV installation structures makes 70-75 % of the overall adapter weight. The lateral dimensions of the platform exceed two times the diameter of the compartment.

Dimensions of the adapter platform for SSV installation exceed the diameter of LV attachment ring. In this case, the platform reinforcement devices should ensure a minimum weight of the structure complying with the stiffness requirements for SSV attachment sites

Adapter structure diagram is calculated both for action of flight and ground loads: adapter is lifted using hoist fittings during handling and integration operations.

In this case weight parameters of the adapter platform depend on the location of hoist fittings and the way of load transfer from hoist fittings to the platform.

Loads from SSV are taken up by beam structure under the most optimal scheme since SSV mounting supports are located in the center and along the edges of the platform in the sites where parts of the intersecting primary beams form rectangular planform structures. Loads are distributed from the adapter platform to its casing, which also results in optimization of the structure diagram (Figure 16).

To arrange hoist fittings on the secondary beams and reinforce them with beams connected to the primary ones and the platform is the optimal structure diagram for load accommodation during ground operation of the adapter. With the use of a structured approach it is possible to create platform-type adapters to launch various quantities of SSV located in one and two-tiers (Figure 17).

Multiple launching includes formally concurrent launch of SSV together with primary SV, for which LV is selected and all launching conditions (time, orbit parameters) are determined. Weight parameters of concurrent SSVs in this case and adapter weight are calculated with regard to the primary SV weight and the LV power constraints.

Primaryo SV is usually installed on the LV standard compartment (often employed as LV instrumentation compartment), secondary SSVs are also mounted on the LV compartment (or rod frame), but with the help of special adapter (Figure 8).

In this case the main tasks of SSV adaptation for launching are:

- ensuring preset stiffness constraints for rod frame to preserve vibration modes in the sites of control system instruments attachment;
- preserving the payload area under LV fairing to the uttermost to provide for primary SV installation.

The ways to solve the posed tasks are as follows (Figure 18):

- to install support brackets for adapter platform attachment in the vital components of the rod frame, having support brackets of primary SV separation system inside them;

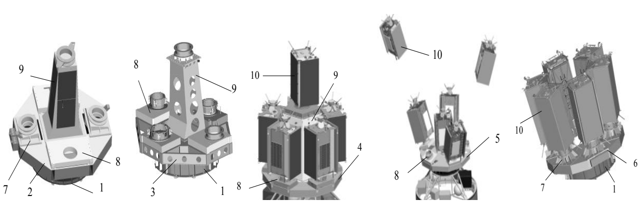


Figure 17. Multipurpose Platform-type Adapters. 1 – LV attachment compartment with shock absorbers (base structure); extension structures: 2,3 – adapter platform for two-tier installation configuration of five SSVs; 4 - adapter platform for two-tier installation configuration of six SSVs; 5, 6 - adapter platform for one-tier installation configuration of six SSVs with and without turntables; 7 - SSV support bracket inclined to the longitudinal axis; 8 – turntable; 9 – rack with shock absorbers to attach the second tier SSVs; 10 - SSV.

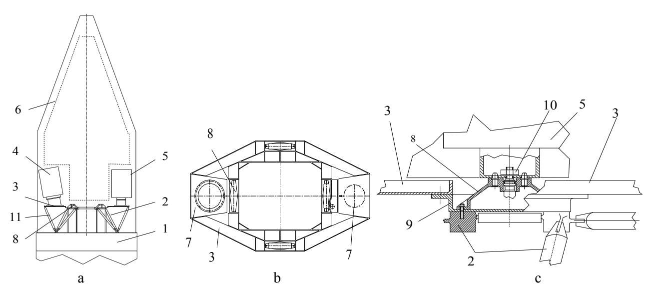


Figure 18. Installation of SSVs to be launched concurrently with the primary SV a – layout for SSV and SV installation on the adapter; b – adapter platform for secondary SSV; c –adapter platform attachment structure 1 – LV instrumentation compartment; 2 – LV rod frame; 3 – adapter platform; 4,5 – secondary SSVs; 6 – primary SV location area KA; 7 – SSV placement sites; 8 – support bracket of primary SV separation system; 9 – attachment adapter support bracket; 10 – pyrolock (charge-driven piston mechanism); 11 – rod racks.

- to align outboard parts of adapter platform toward the rod frame attachment points and support them with V-shaped rod racks, bound ends of which are attached on the support brackets of the instrumentation compartment to fix the rod frame;
- total height of support brackets for adapter platform attachment and the platform itself should not exceed the height of support brackets for primary SV installation.

During concurrent launch of two SSVs the adapter platform acts as a base structure. Support brackets, turntables and separation systems, mounted on the adapter platform are extension structures, their design is determined by the SSVs to be launched (Figure 19).

Adapter packaging integrated with the last stage of LV (or SUS) makes it necessary to reduce vibration and shock loads (Figure 8). These loads greatly depend on mutual location of the adapter, SUS and on the structure diagram, providing their connection to each other and transfer of flight loads from LV.

It is expedient to integrate adapter packaging with SUS, in this case loads are transferred from LV to SSV bypassing the SUS structure (Figure 20).[18]

Tasks for parameter optimization of "SUS + adapter" system include:

- to increase SSV placement area under LV payload fairing;
- to reduce vibration and shock loads on the installed SSV and electronic instruments of SUS;
- to extend the range for variation of damping properties of adapter and SUS structure.

The ways to solve the posed tasks are as follows[18]:

- adapter with the first tier SSV attachments and adapter rack for the second tier SSV installation are made in the form of annular platform and located in the upper part of SUS around its instrumentation compartment;
- annular platform of the adapter is fixed ring by means of interface ring on the adapter section intended for attachment with LV;
- SUS is suspended inside the adapter section using junctions fixed on the SUS instrumentation compartment and on the adapter section in the site located below the attachment of the adapter section with the adapter;
- damping components (shock absorbers) are mounted in the junctions of interface rings of the adapter section with the adapter and adapter section with SUS.

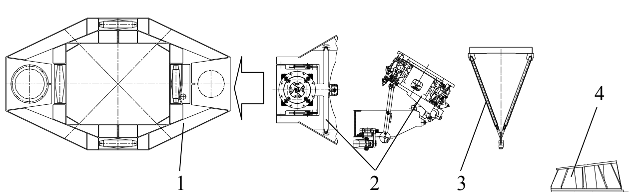


Figure 19. Adapter Shaping Circuit for SSV Concurrent Launch 1 – adapter platform for SSV concurrent launch – base structure of the adapter; extension structures: 2 – separation system with or without turntable; 3 – platform struts; 4 – support brackets for angular installation of SSV.

Depending on the amount of loads acting on the part of LV, quantity of the launched SSVs, their size and weight, requirements to reduce loads on the SSV electronic instruments and SUS control system instruments various SSV attachment configurations may be implemented during multiple and single launching (Figure 21).

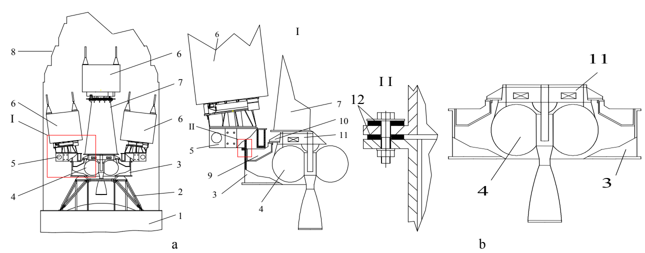


Figure 20. Adapter Packaging Integrated with SUS a – design and layout; b – base structure of the adapter 1 – LV; 2 – LV frame; 3 – adapter section; 4 – SUS; 5 – annular adapter platform; 6 – SSV; 7 – adapter rack; 8 – SSV area; 9, 10 – SUS attachments; 11 – SUS instrumentation compartment; 12 – shock absorbers

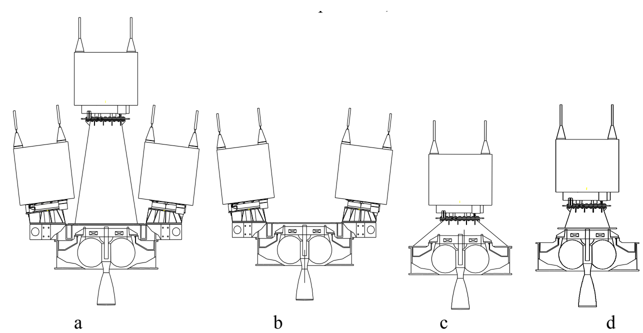


Figure 21. Multipurpose Adapters with SUS a – combined layout: 'peripheral + central' installation of SSV; b – peripheral installation of SSV; c, d – single layouts for SSV installation on the adapter section and instrumentation compartment of SUS.

Mechanical loads are transferred directly to SSV via mechanical junctions where damping components are installed. In addition, attachment scheme of annular adapter platform and SUS excludes their mutual power impact as much as possible. Weight of SUS with SSV installed thereon is eliminated from the damped weight of the annular adapter platform.

Mechanical loads are transferred to SSV located coaxially with SUS via adapter section, mounting brackets and casing instrumentation compartment SUS. In this case the structure of SUS of the suspension scheme works in tension and is under lower loads.

Weight of the annular platform of the adapter with SSV installed thereon does not influence load transfer to SSV located in the center. Control system instruments mounted in the SUS instrumentation compartment will undergo loading only from the weight of SSV located in the center.

If loads transferred from LV are unacceptably high for SUS control system instruments, central SSV may be installed directly on the adapter section.

Side installation of SSV on the adapter is widely used in the practice of single launcher placing several SSVs on orbit; this method automatically provides shockless separation of SSV.[6] Applying structural approach creation of multipurpose adapters of a truss type for launching from two to six SSVs is ensured by incorporating truss structures for installation of two and four SSVs (Figure 22).

In addition, to provide stability and controllability of LV at the site of insertion into orbit by complying with the requirements for longitudinal center of gravity of the adapter with SSV it is possible to create an adapter with combined SSV installation configuration (side and end ones) (Figure 23).

5. Discussion

The conducted tests have shown:

1. Structural approach applied using base and extension structures allows creating adapters for multiple and concurrent launch of SSV with flexible and extensible structure resulting in quasioptimal design parameters.
2. For rod and shell adapters LV attachment ring (or compartment, concurrent launching platform) is a base structure ensuring mechanical and electrical coupling, reduction of mechanical loads on SSV.
3. It becomes critical to reduce mechanical loads on SSV when adapting already existing SSVs to LV with higher operational loads placing multiple SSVs into their orbits; this task is solved by incorporating shock absorbers into LV attachment ring structure that can also be mounted in the SSV installation sites.
4. Adapter platform structure for SSV end installation makes 70-75 % of total weight of adapter structure and to obtain quasioptimal weight parameters of adapter it is referred to extension structure developed for a definite multiple launch of SSV.
5. Extension structures also include turntables, separation systems, SSV installation support brackets, reinforcing components; second tire SSV installation racks, additional platforms for SSV installation.
6. To retain the existing parameters of LVs used for SSV launching and to solve the tasks of multiple and concurrent launch by developing high-efficient design and engineering solutions for adapters and SSV is the primary principle for adapter creation, for example:

- codesigning of adapter and SSV: weight of “adapter + SSV” system is reduced down to 20%, packaging density increases up to 30-40%;
- developing SSV with possibility to attach to adapter according to end and side installation configuration: the number of the installed SSV increases from three to four compared to the known configurations; fairing length and weight is reduced down to 50 %;
- incorporating shock absorbers: the level of accidental vibrations considerably decreases in the frequency range from 60 Hz to 2500 Hz, root-mean-square amplitudes of accidental vibration decrease by 2.5-3 times, level of shock loads during SSV separation decreases by 6-10 dB;
- making adapter in the form of a truss, with the side mounting surfaces of the truss being positioned perpendicular to and inclined to the LV attachment plane: this provides LV lateral center of gravity, and shockless separation of SSV is ensured by the SSV side separation configuration;
- making adapter platform in the form of a beam structure with SSV mounting surfaces being positioned in the center and along the platform edges in the sites, where parts of the intersecting primary beams form rectangular planform structures; positioning hoist fittings on the auxiliary beams located between the outermost mounting surfaces for SSV installation

and reinforcing them with beams connected to the primary beams and the platform: adapter structure weight is reduced by 20-25 %;

- using turntables to fix SSV for end configuration of attaching SSV to the adapter: they provide high packaging density of SSV as part of the LV and shockless separation of SSVs from the platform by turning SSV to a safe angle;
- conducting ground and flight development tests of turntable as part of the flight adapter when preparing and performing demonstration launch of SSVs: cost for turntable developmental testing are cut down;
- using platforms – adapters installed around the primary LV by means of standard units for SV rod frame attaching to LV for SSV concurrent launching: structure weight is reduced by 25-28%, the preset parameters of platform-adapter stiffness are provided, rod frame stiffness parameters are retained, which excludes testing to confirm non-exceedance of dynamic loads in the attachment sites instruments control system LV, the existing primary SV placement areas are preserved below LV payload fairing.

7. Incorporation of SUS into the adapter (combined packaging of adaptera and SUS) allows solving many problems of orbital maneuvering: elimination of orbit insertion errors, of operating orbit maintenance, SSV dispensing, inter-orbital maneuvering, adapter deorbiting for utilization, etc.
8. SSV and SUS vibration and shock loads greatly depend on mutual location of adapter, SUS and structure diagram ensuring their connection to each other and transfer of LV loads acting during the flight;
9. Combined adapter and SUS packaging is expedient; in this case loads are transferred from LV to SSV bypassing SUS structure.
10. Depending on the value of loads acting from the part of LV, quantity of launched SSVs, their size and weight, requirements for reducing loads SSV electronic instruments and SUS control system instruments, multipurpose approach allows implementing various SSV attachment configurations during multiple (up to six SSVs) and single launches.
11. Combined adapter and SUS packaging provides:

- reduction of structure weight by 25-30% by suspending SUS and reducing the weight of damping units due to decrease of the damped weight;
- increased SSV installation area under payload fairing by positioning SUS below SSV mounting surface and installing annular adapter platform around SUS instrumentation compartment;
- more efficient use of shock absorbers installed in the joints between adapter section and adapter and between adapter section and SUS.

12. For side installation of SSV multipurpose adapters of a truss type to launch from two to six SSVs are created by incorporation of truss extension structures to install two and four SSVs thereon.
13. Requirements for LV stability and controllability at the orbital insertion site extending the adapter possibilities are complied with by means of creating an adapter with combined SSV installation configuration (side and end ones) and incorporating extension platform for end installation of SSV.

6. Conclusion

1. Development of multipurpose adapters with flexible and extensible structure applying structural design method allows obtaining quasioptimal design parameters for adapters when solving various target tasks for SSV launching.
2. The intended use of the multipurpose adapters under consideration is determined by the extent of difference of the target tasks to be solved and implies launching two, four and six SSVs.
3. Elimination of modifications for LV used to launch SSV is the main principle during multipurpose adapter creation by means of developing high-efficient design and engineering solutions for adapters and SSV.
4. Mutual influence of design parameters of SSV, adapter and LV employed for launching is a distinctive feature of creating multipurpose adapters. Best results are obtained during combined designing of adapter and SSV for multiple launching by a specific LV.
5. The presented adapter design layouts prove technical feasibility to create high performance multipurpose adapters.

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