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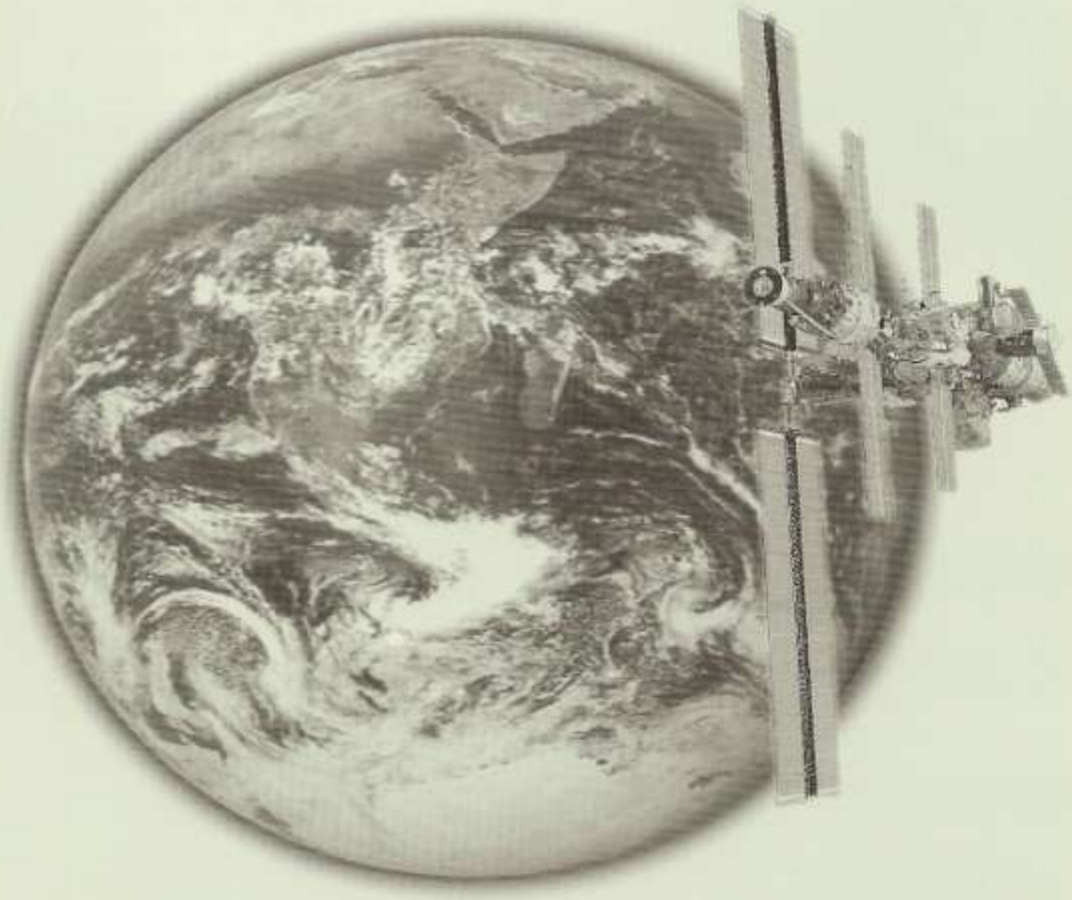

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Advanced Reentry Vehicles

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SUPERLIGHT REENTRY VEHICLES [☆]

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Abstract

One of the essential problems in the development of Orbit-to-Earth transportation systems is the maximization of the mass perfection and the reliability of the reentry vehicles with the minimization of the project costs [H. Ruppe, *Introduction to Astronautics*, vol. 1, Verlag Nauka, Moscow, 1970]. This paper proposes an analysis of an Orbit-to-Earth transport system based on the use of "superlight reentry vehicles" (SRV). The specific load of the SRVs range from 3 to 12 kg/m^2. The structure of the SRVs employs gas-filled plastics with density ranges from 12 to 150 kg/m^3. This paper presents the morphological table to be used with "superlight reentry vehicles", designed to examine the possible spheres of existence and use of these capsules. In this report, the following types of vehicles are investigated: Superlight controlled reentry vehicles; Superlight ballistic reentry vehicles; Use of inflatable designs; Interplanetary missions. The results of ballistic and mass simulation are presented. SRVs can correct reentry (up to 80 km) and choose a landing place. This paper describes the proposed design of the capsules and compares them to those currently in existence. It is shown that using the proposed vehicles enables the achievement of high values of payload ratio (up to 54%). In this report, a design of such vehicles and their comparison with existing vehicles is presented. We also present the calculation for the aerothermodynamic performance. © 2004 Lister Science.

Keywords: Superlight Reentry Vehicles; Aerothermodynamic; Orbit-to-Earth

1. INTRODUCTION

One of the most important tasks in the sphere of development of the "SPACE–EARTH" transport systems is to increase the mass efficiency of reentry vehicles whilest also achieving an increase in system efficiency and the reduction of the exploitation costs [1,2,7,8]. Existing transport systems have mass efficiencies (ratio of payload mass to overall mass of RV) from 2–3% to 40%.

Previous publications [3,4] study the RV conception, which have the following characteristic features:

> Small midship section load (ratio of RV mass to area of midship section)—from 1 to 5 kg/m^2.
> The absence of a parachute system, as at low specific load the landing speed is from 5 to 18 m/s (from 11 to 40 miles per hour).

1.1. *Research into the Array of "Reentry Vehicles"*

The research method utilized is based on the theory of system morphological [4,10] and cluster analysis, methods of mathematical simulation, and experimental calculation are performed using computers. The specifics of the structural synthesis analysis are via the discrete character of variables and the presence of conditional and logical limits. This is added due to the necessity to work with several contradictory criteria. The essence of this design study is to systematically vary the attribute values to determine the variants that produce a better performance than originally obtained.

The algorithm of the design calculation for the sequence of calculation operations for finding the criterion is shown as the end function. This function does not satisfy the main requirements of theoretical optimization methods as it is discrete, it cannot be always calculated; it exists in the statement representation; it is not differentiable, not unimodal, not separable, and not additive. Its other characteristic feature is that it is impossible to simulate analytically the hypersurface of the end functions and to prognosticate

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Table 1
Morphological box "superlight reentry vehicles"

Descriptors/elements	Element 1	Element 2	Element 3	Element 4
Form	sphere 1	**blunt-nosed body**	Cone	Sojuz- form p
Specific load	<10 kg/m²	**10–100 kg/m²**	1000–200 kg/m²	>200 kg/m²
Landing system	No	Parachute system	**Expandable structure**	Paraglider landing system
Control	Controlled reentry vehicles	Controlled reentry vehicles (rolling)	**Uncontrolled ballistic reentry vehicles**	Uncontrolled reentry vehicles with lift–drag ratio
Control system	Self-contained system	External system	**No**	
Integration with satellite	**No**	Satellite–RV	Element of satellite	
Modification of form	**Yes**	No		
Application	Investigation of planetary atmosphere	Investigation of ballistic data	Reentry vehicles	**Retrieving of system elements**

Boldtype=The technical solutions—IRDT (inflatable reentry and descent technology).

this change on the each variable step increase. Instead of a step-by-step movement in the attributes' space, this method proposes a zone examination with the help of clusters. As a result, our investigation generates the morphological table together with complimentary tables (Table 1).

All the variants are analyzed according to their degree of similarity. According to the procedures' results, the set of preoptimal clusters (variants) is formed. For each cluster (variant), the level is calculated. The research fields now only include preoptimal clusters (variants). The best variants are included into the final table. Thus, it is possible to evaluate the novelty of the synthesized variants. The evaluation is based on the concept of the degree of similarity. Finally, the methodology involves a design of structural TS schemes («white boxes»). They consist of element models and structural models. The procedure was used to solve the problem of searching for the new construction and arrangement of the schemes of the RV. The modification of the focal object method and an inverse approach were used to form the initial set of elements. The variant number for the elements used was 451 584.

At cluster 2 (see Fig. 1), there are four technical solutions with relatively high values [4]. The essence of the technical solutions is that the mass accelerators are used for the deceleration.

Therefore, it is possible to draw the conclusion that the studied RV has the following advantages:

- decrease of heat and velocity flows lead to the decrease of RV mass, and therefore the share of useful load (mass efficiency) increases;

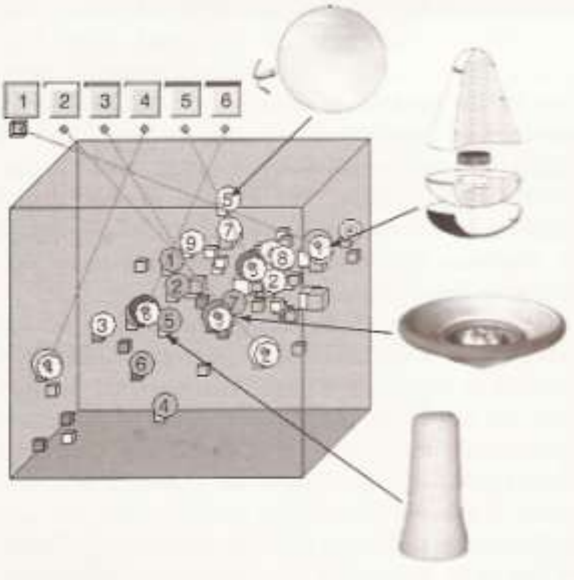

Fig. 1. A three-dimensional classification field of RV.

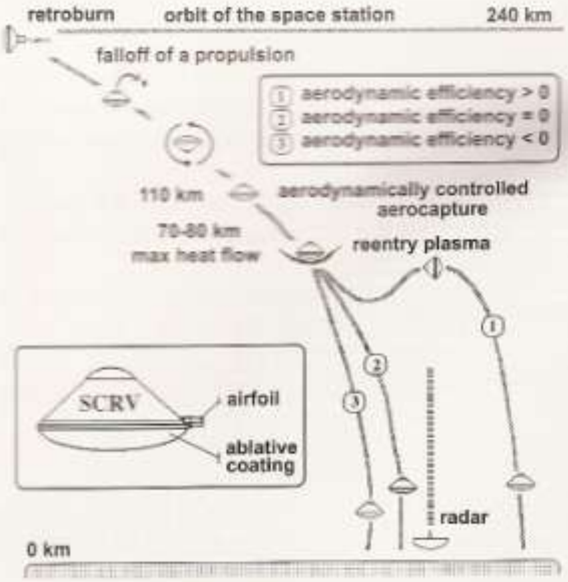

Fig. 2. Flight path of SCRV.

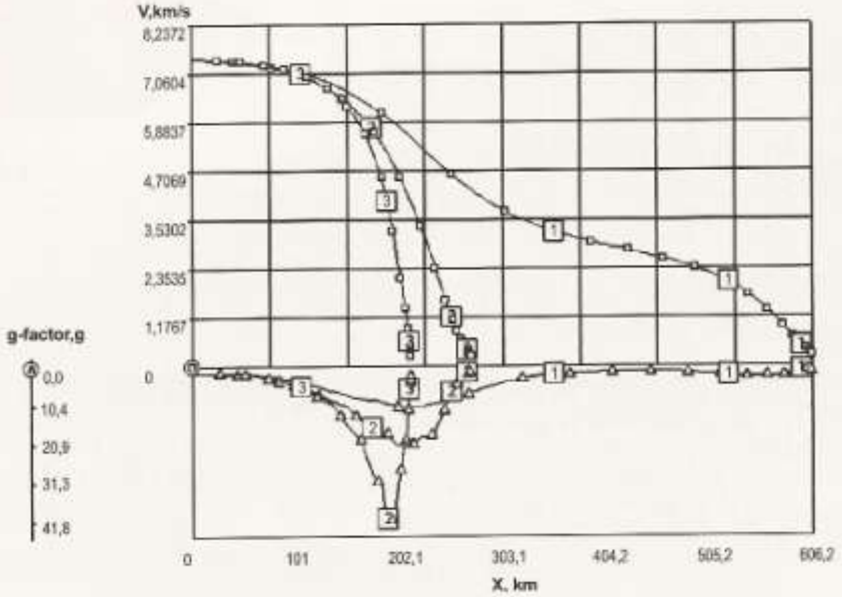

Fig. 3. Flight path of SCRV.

- decrease of RV construction mass due to the absence of deceleration devices.

After the methodology was applied, a certain set of technical solutions for RV were left. Among them was a superlight RV (SRV) (cluster 1).

2. CLUSTERS "SUPERLIGHT REENTRY VEHICLES"

The following types of RV are investigated

- Superlight controlled reentry vehicles.
- Superlight ballistic reentry vehicles.

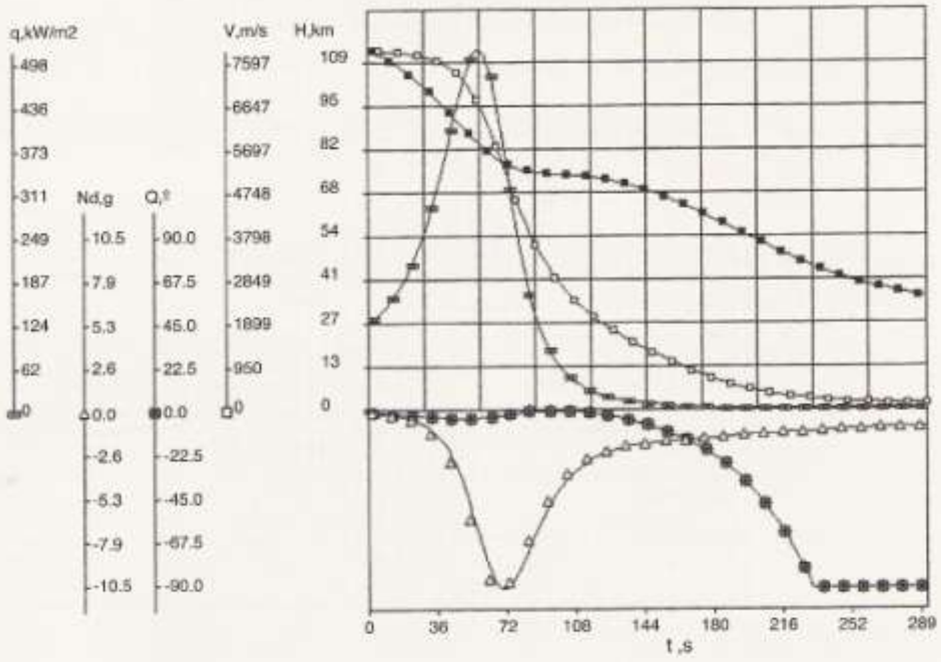

Fig. 4. Flight path of SCRV.

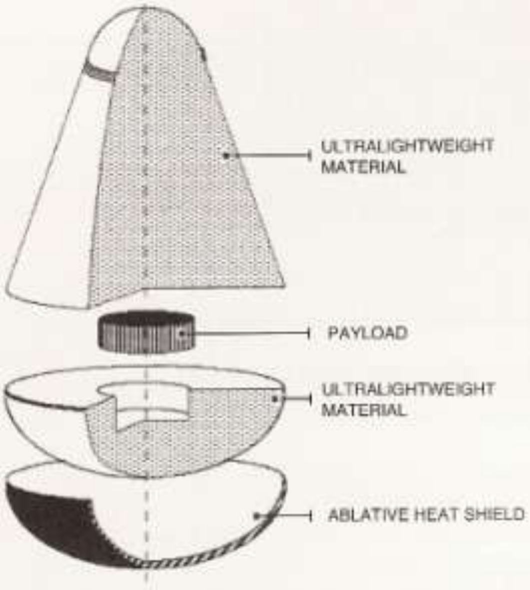

Fig. 5. Ballistic SRV.

- Interplanetary missions.
- Use of inflatable designs (small specific load)—Inflatable Reentry and Descent Technology.

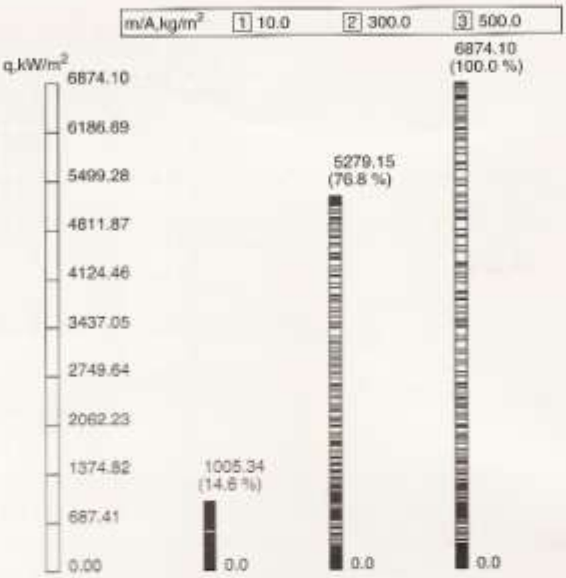

Fig. 7. Heat flow for ballistic SRV.

2.1. Superlight Controlled Reentry Vehicles (SCRV)

The specific load of the SCRVs ranges from 3 to 12 kg/m². The structure of the SCRVs uses gas-filled

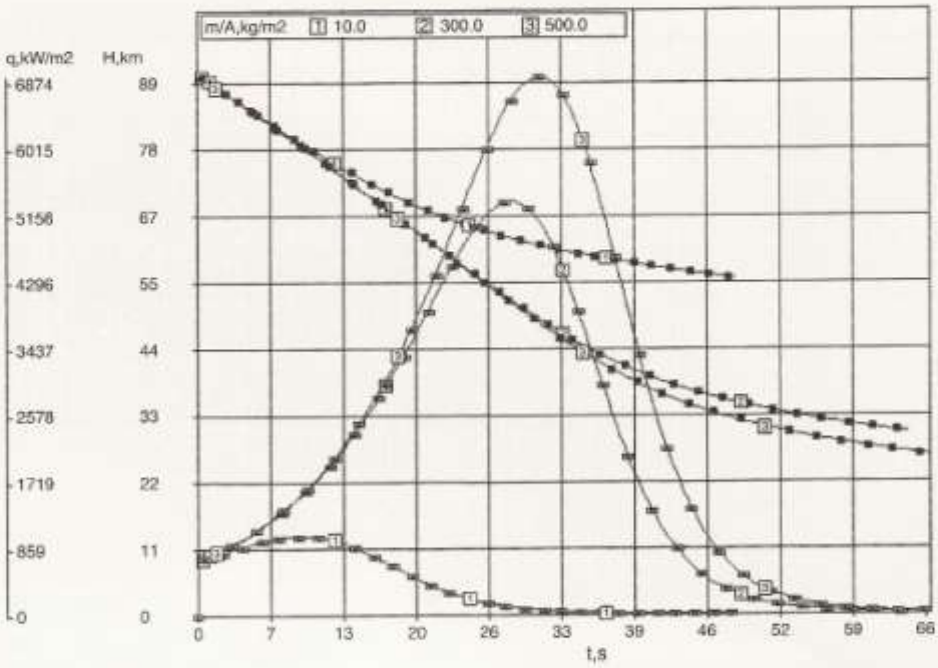

Fig. 6. Trajectory characteristics for ballistic SRV.

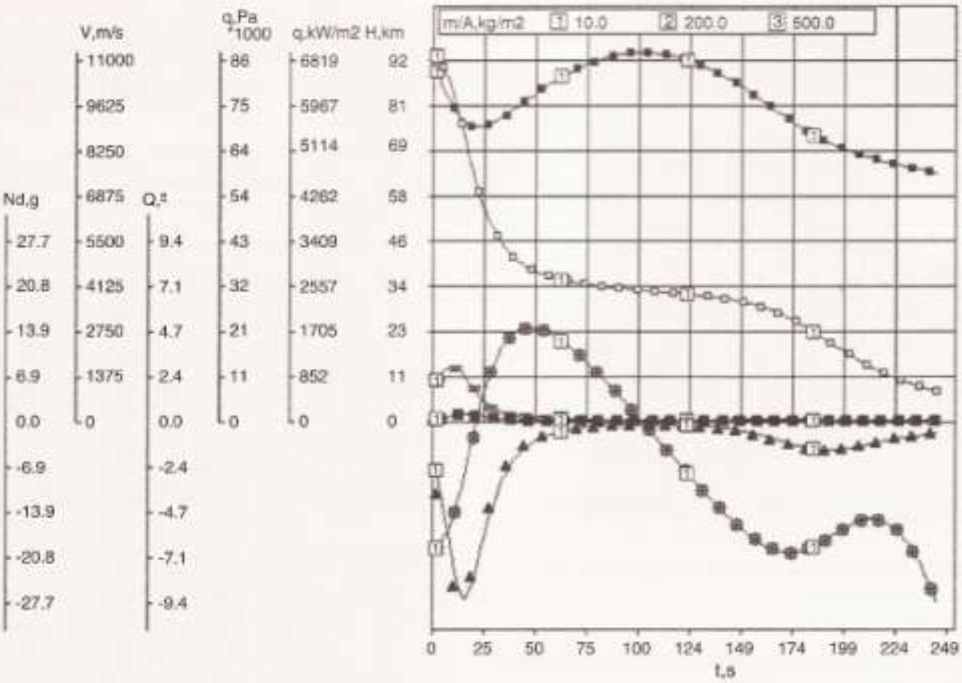

Fig. 8. Trajectory characteristics for interplanetary SRV.

plastics with density ranges from 12 to 150 kg/m^3. The results of ballistic and mass simulation are presented in Fig. 2.

SCRVs can correct reentry (up to 80 km) and then choose a landing place. The report describes the proposed design of the capsules and compares them to those currently in existence. It is shown that using the proposed vehicles allows us to reach high values of payload ratio (up to 54%). Use of the morphological table for "superlight controlled reentry vehicles", enables the possible spheres of existence and the use of these capsules to be evaluated (see Figs. 3 and 4) [3].

2.2. Superlight Ballistic Reentry Vehicles

Superlight ballistic reentry vehicles have a smaller weight in comparison with SCRV. Their disadvantage

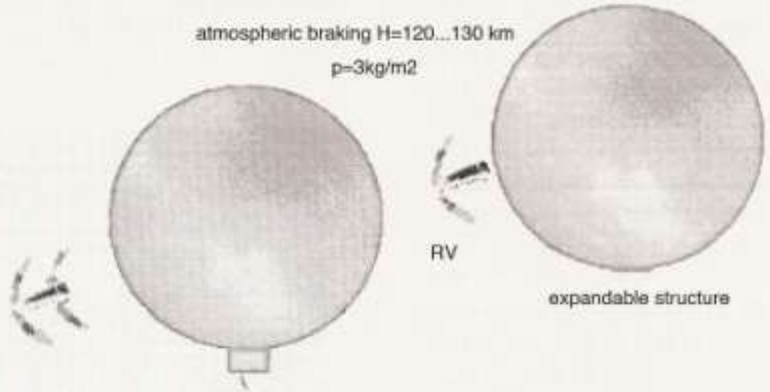

Fig. 9. Exit from orbit for RV.

Fig. 10. Reentry drag balloon (prototype).

is a poor landing accuracy. The characteristics of these SCRV capsules are shown in Figs. 5–7.

2.3. SRV for Interplanetary Missions

The characteristics of interplanetary vehicles are shown in Fig. 8.

2.4. The Use of Inflatable Designs

2.4.1. Millennium Project (1999, G.V. Malyashev, Moscow State Aviation Institute)

The RV in the Millennium Project was equipped with an inflatable sphere. Using this sphere raised the accuracy of RV landing (Figs. 9 and 10).

2.4.2. Inflatable reentry and descent technology

In high-speed approach landings on distant planets having an atmosphere, space probes are usually protected by rigid heat shields, while their descent is slowed down by parachutes to reduce the impact. In recent years, new technologies have been developed to replace these bulky shield and parachute systems [7,8].

The Russian spacecraft Mars '96 for instance, which was launched in November 1996, but failed to reach its nominal orbit, carried two modules designed to land on the planet's surface. For the last part of the mission, an inflatable reentry and descent technology (IRDT) was deployed. The main components of the system were an aerobraking and thermally protective shell, a densely packed inflating material, and a pressurization system.

The Russian/European Starsem launch company and NPO Lavochkin, the Russian company that developed the original IRDT technology, were responsible for the launch, orbit control, reentry, and recovery of the sensor package under contract with the International Science and Technology Center (Moscow).

The IRDT landed inside the predicted area at 54°E longitude and 51°N latitude near the Kazakhstan border. Due to the higher velocity, the impact upon the ground was heavier than expected resulting in some damage to the lower part of the IRDT containing the housekeeping equipment and the beacon. After 4 days of bad weather conditions with snow and fog in the landing area, it was not until February 14 that a helicopter was able to resume the search and finally pick up the IRDT. The memory unit of the sensor package with all recorded data is now being analyzed by experts and compared with the data collected by Russian mission control. Initial data check confirmed that all experiments in the sensor package worked perfectly (Fig. 3) [7,8].

The inflatable reentry and descent technology (IRDT) concept consists of an extremely light, modular system that can be adapted to any space element and is launched into orbit in a folded state. IRDT is an innovative heat shield that inflates shortly before reentry into the Earth's atmosphere and will then act as drag parachute.

Unlike conventional systems (e.g., Shuttle, capsules), the heat shield need not be delivered into space in its final configuration, a fact that will save space, weight, and thus transport fees. The three main reentry subsystem elements are combined by the IRDT technology, i.e.,

- thermal protection system (TPS) for reentry,
- parachute system for descent,
- damping/floatation system for landing.

Fig. 11. IRDT inflated for pre-flight inspection.

Fig. 12. IRDT-Design [7,8].

This results in a simple, cost-effective design of a reentry system, which will provide sufficient aerodynamic and aerothermodynamic behavior during the critical reentry phase and will allow for touch-down of the vehicle in the predefined landing area. The IRDT system consists of three typical mission configurations: the inflatable material is densely packed during launch and orbit phase making optimum use of the space available.

The flight configuration will be placed into the reentry trajectory with retrograde firing of a suitable motor. Before entering the upper layers of the atmosphere, the first cascade of the IRDT will be inflated by gas, released through a pyrovalve from the storage tanks of the pressurization subsystem or a gas generator. The inflatable braking shield consists of different layers of multilayer insulation and flexible ablative layers arranged on a flexible inflatable kernel. This kernel provides the form and stiffness of the inflatable braking shield that performs aerobraking to subsonic speed while flying through the atmospheric layers. The aerobraking shield provides sufficient aerodynamic stability during all reentry flight regimes. For braking to moderate landing velocities, the second cascade will be inflated. This further increases the braking area and replaces the parachute. Depending on the shock requirements for landing, a damping system may be added to the configuration.

3. RESULTS

As a result of cluster "SRV" study, the following conclusions were drawn.

First, the vessels belonging to the cluster "SRV" are characterized by the following features:

- low midshipsection load—from 5 to 40 kg/m^2 (superlight materials are used);
- small LS mass (form 1 to 20 kg);
- absence of parachute system, as at low specific load the landing velocity is from 5 to 18 m/s.

Second, SRVs have the following advantages:

- higher system efficiency due to RV adaptation to the production characteristics;
- increase of mass efficiency up to 50–60% due to the absence of the landing system as well as to the decrease of the heat and velocity heads influencing the RV.

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