Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 36, 2024, Sofia

DOI: https://doi.org/10.3897/arb.v36.e17

IMPACT OF SPACECRAFT AND ISS ENGINES ON EXPERIMENTAL SAMPLES OF VARIOUS MATERIALS MOUNTED ON THE OUTER SURFACE OF THE "ZVEZDA" MODULE

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Keywords: *Spaceships, Engines, Gas jet, Experimental samples*

Abstract

The work presents a study of the influence of the spacecraft and ISS engines during the correction of the station's orbit. The zones of action of the gas jets and their impact on the environment and the surfaces of the experimental samples of various materials mounted outside the "Zvezda" module were determined.

Introduction

The development of scientific equipment for the exploration of outer space on board satellites and space stations requires the creation and testing of new materials that can withstand the stresses of operating in the conditions of open space, such as high and low temperatures, vacuum, exposure to ionizing radiation, microparticle flows, etc. All these outer space factors adversely affect the materials from which spacecraft and scientific equipment are made. As a result, various physico-chemical and mechanical processes occur in the materials used, leading to a deterioration of their parameters. Depending on the nature of the processes caused by the impact of the space environment, near the board of satellites and orbital stations, with scientific equipment mounted on them, the surface properties of materials can change, leading to reversible and irreversible processes.

To acquire complete and real data on the effects of these processes, a technological experiment was planned and carried out in cooperation with a leading country in this industry - the Russian module of the International Space Station (ISS), in whose division the team with the block "DP- PM" as part of the "Obstanovka 1-step" experiment. A "DP-PM" block is a container measuring 185 mm × 70 mm × 10 mm (Fig.1) [1].

Method

The experiment to study the influence of the space environment on the structure and properties of various samples was conducted from 04.19.2013 until 10.08.2015. The operation of the "DP-PM" block from its placement on the outside of the Zvezda module until its delivery to Earth is carried out following the documents of Product 17KS #12801. P42422.

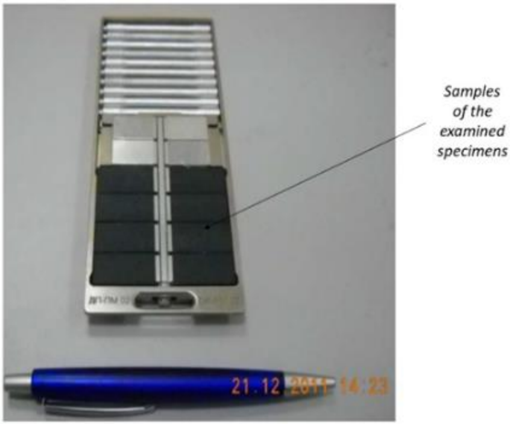


Fig.1. Block "DP-PM"

The experiment's purpose is to study surface degradation and structural changes occurring in graphite samples densified and coated with glassy carbon (GC) during prolonged stays in outer space conditions [1,2].

Fig. 2 shows the exact location of the "DP-PM" block on the surface of the ISS [3].

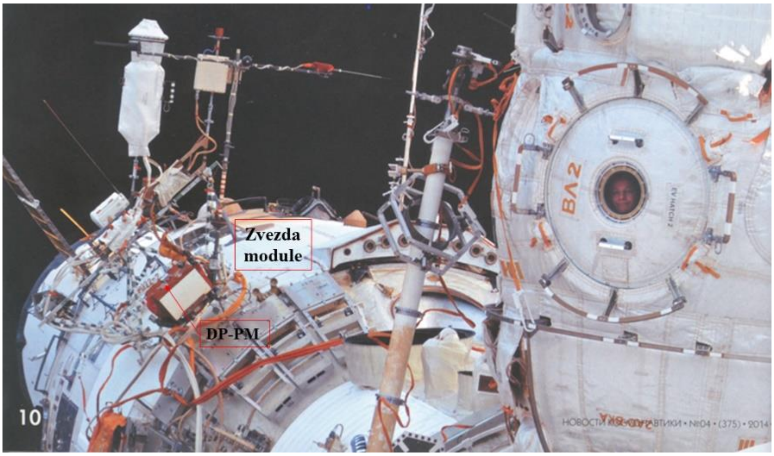


Fig. 2. The exact location of the "DP-PM" block on the surface of the ISS [3]

After completion of the planned period, the "DP-PM" block is dismantled from the outer surface of the ISS and the cosmonauts place it in a work bag (Fig. 3a). Then, in the transition compartment of the Zvezda module, the cosmonauts put it in a special soft container (Fig. 3b). In preparation for returning to Earth with the Soyuz-TMA spacecraft No. 716, the container was additionally placed in an airtight transport package (Fig. 3c). In this type, the "DP-PM" block was handed over for conducting research at the Space Research and Technologies Institute at the Bulgarian Academy of Sciences (SRTI–BAS).

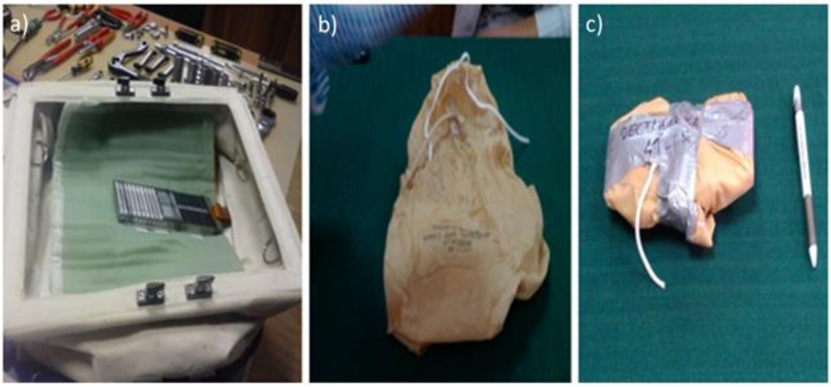


Fig.3. Different types of packaging for transporting a DP-PM block:
a) Work bag; b) Special soft container; c) airtight transport package

Upon external inspection of the samples (Fig. 4), it was found that their surfaces are heavily blackened, which suggests an atypical impact on them in the conditions of the space vacuum and weightlessness of this orbit. Our working hypothesis was that the condition of the surface of the samples was due to the impact of the gas jets from the various engines used in the control and correction of the ISS, both during the docking of the ships coming from Earth and their separation from the ISS.

Fig. 4. Appearance of the samples from block "DP-PM" during research at SRTI–BAS

After March 2011, a total of 15 pressurized modules were added to the ISS: Zarya, Zvezda, Destiny, Unity (Node1), Harmony (Node2), Tranquility (Node3), Columbus, Leonardo, Japanese, Quest, Cupola, Poisk, Rassvet and Pierce. To these modules we can add all three pressurized docking adapters. We note that after the completion of the flights of the "Space Shuttle" program, the orbit of the station was raised from 350 km to 390–420 km.

In order to study the influence of the gas jets of the engines on the samples, in addition to their location, also the modes of docking (de-docking), control and corrections of the ISS by the ships and the Zvezda module were taken into account.

The scheme presented below (Fig. 5) depicts the main components of the station and the ships arriving (departing) to it, as well as the location of the main and correction engines (red arrows) [4].

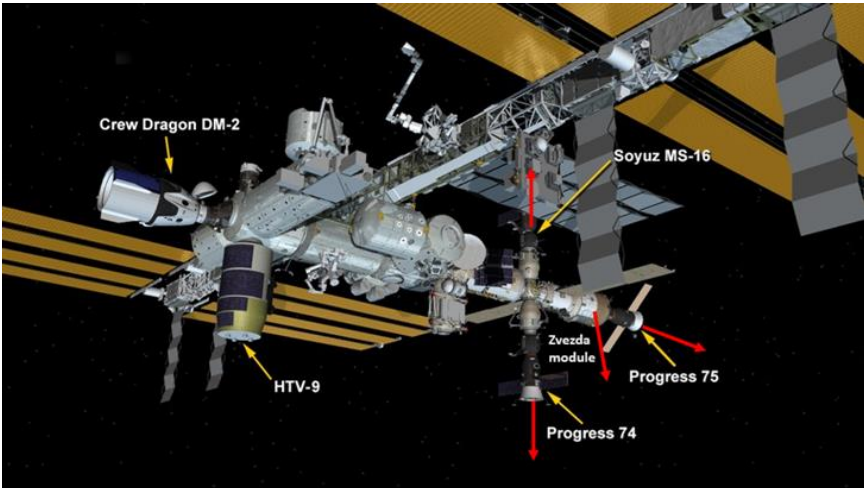


Fig. 5. Schematic of the main components of the ISS and the spacecraft docked to it [4]

The height of the station's orbit is constantly changing due to the influence of solar activity and friction with the rarefied atmosphere, which leads to the gradual deceleration of the movement and loss of height. Atmospheric drag lowers the altitude on average by about 2 km per month [5].

The graph of the change in the height of the ISS, including the period of the experiment, is shown in Fig. 6 [6].

The ISS's orbit is adjusted several times a year to compensate for friction, to avoid larger and larger pieces of space junk, and for other reasons. Orbit correction is done using the ISS's own engines. Until 2000, the engines of the Zarya functional cargo model were used for this purpose, and then - of the Zvezda service model. The engines of the arriving transport ships are also used for orbit correction, which also refuel the ISS [6]. Up to a certain period of time, the correction in the orbit only compensates for the decrease in altitude.

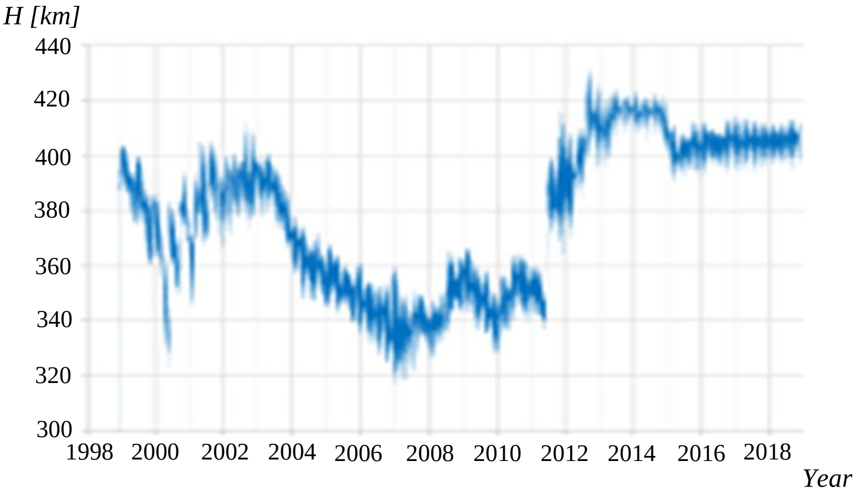


Fig. 6. Diagram showing the change in height of the ISS for the period from 1998 to 2018 [6].

Research shows that using Space Shuttle craft to maintain a 350 km high orbit of the ISS required 8 600 kg of fuel for one year. When increasing the height of the station's orbit to 400 km, the required fuel is 3 600 kg. During this period, the fuel for control and orientation was 1 926 kg [7]. The increased altitude allows for a substantial reduction in the amount of fuel required to maintain this orbit. At the same time, it enables increased supplies of water and food products, as well as other payloads. The ISS completes a complete orbit around the Earth in about 92 minutes. From launch to February 5, 2023, the station has completed 138 805 complete orbits.

During the experiment, the following spacecraft were flown to the ISS and docked with the station: Soyuz, Progress, and Cygnus. The results are shown in Tables 1, 2, and 3.

Table 1. Soyuz spacecraft flights

By №	Mission Name	Board number	Launch date	Date of landing
141	Soyuz TMA-09M	709	05/29/2013	11/11/2013
142	Soyuz TMA-10M	710	09/26/2013	03/11/2014
143	Soyuz TMA-11M	711	11/07/2013	05/14/2014
144	Soyuz TMA-12M	712	03/26/2014	09/11/2014
145	Soyuz TMA-13M	713	05/28/2014	11/10/2014
146	Soyuz TMA-14M	714	09/26/2014	03/12/2015
147	Soyuz TMA-15M	715	11/24/2014	06/11/2015

Table 2. Progress spacecraft flights

By №	Mission Name	Board number	Launch date	Date of landing
142	Progress M-19M	419	04/24/2013	06/19/2013
143	Progress M-20M	420	07/28/2013	02/11/2014
144	Progress M-21M	421	11/26/2013	06/09/2014
145	Progress M-22M	422	02/05/2014	04/18/2014
146	Progress M-23M	423	04/09/2014	08/01/2014
147	Progress M-24M	424	07/24/2014	10/27/2014
148	Progress M-25M	425	10/29/2014	04/26/2015
149	Progress M-26M	425	02/17/2015	08/14/2015
150	Progress M-27M	426	04/28/2015	05/08/2015
151	Progress M-28M	428	07/03/2015	12/19/2015

Table 3. Cygnus spacecraft flights

By №	Mission Name	Spacecraft name	Launch date	Note
1	Cygnus Orb-D1	George Lowe	09/18/2013	First Cygnus spacecraft mission. The first Cygnus docking mission with the ISS was delayed due to a computer problem but was successful.
2	Cygnus Orb-CRS-1	Charles Fullerton	01/09/2014	First logistics mission of a Cygnus spacecraft.
3	Cygnus Orb-CRS-2	Janice Voss	07/13/2014	
4	Cygnus Orb-CRS-3	Donald Slayton	10/28/2014	During the launch attempt, there is a catastrophic anomaly, and the launch vehicle explodes.
5	Cygnus Orb-CRS-4		11/19/2015	The first mission of an enhanced version of Cygnus.

Figure 7 shows the structure of the Soyuz transport ship and the location of the engine bay [8].

The propulsion module of the Progress spacecraft, like that of the Soyuz, is located at the rear of the spacecraft. The module consists of the ship's main engine and navigation engines used for automatic docking with the ISS and for correcting the station's orbit when the ship is docked with it. On these ships, only one set of orientation engines type OE (8 units) with a thrust of 1.5 kgf, a KTDU-35 brake-engine unit with a thrust of 417 kgf and 14 engines for docking and orientation (EDO) with a thrust of 10 kgf were installed. The fuel for KTDU-35 is asymmetric dimethylhydrazine (ADMH) and oxidizer-nitric acid. EDO and OE work with hydrogen peroxide [8].

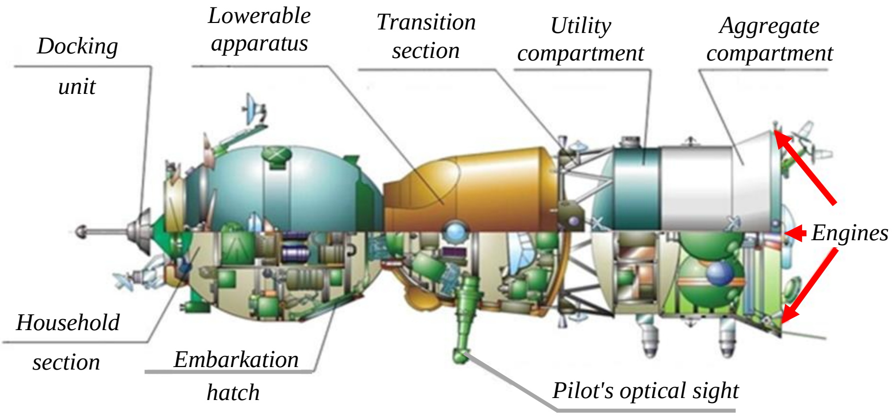


Fig. 7. Construction of the "Soyuz" transport spacecraft [9]

The combined propulsion system, which is used in many cases for orbit correction and control of the ISS [9] consists of two 2×312 kgf thrusters, 32×13.3 kgf thrusters for orientation, 302 kg of propellant (ADMH) and 558 kg of oxidizer (nitrogen tetraoxide).

The Cygnus spacecraft consists of two main components - a service module and a cargo module. The service module has a gross weight of about 1 800 kg and is powered by Japanese rocket engines (BT-4 of the Aerospace company) running on ethylhydrazine and dinitrogen tetroxide [10]. Each motor develops a thrust of 46 kgf (Fig. 8).

Fig. 8. Cygnus spacecraft approaching the International Space Station [10]

After detaching aboard the Antares rocket, Cygnus approaches the ISS, and when within a few meters of the station, the craft is engaged by the Canadarm-2 mechanized arm and docked with the Harmony module. Cygnus does not have the ability to return cargo to Earth, but it can be filled with debris to burn up with it as it enters Earth's atmosphere.

From the beginning of the station's creation until October 2022, the ISS's orbit has been corrected 327 times, 176 times with the engines of the transport spacecraft Progress, which shows the importance and frequency of the correction.

For the period of the positioning of the samples on the outer surface of the Zvezda module (28 months), a total of about 4 550 kg was used (spacecraft Progress – 3 248 kg; modules Zvezda, Cygnus, etc. about 1 302 kg) for correcting the orbit of the ISS for control necessary for avoiding space debris and preparing the station for docking and undocking of arriving and departing spacecraft.

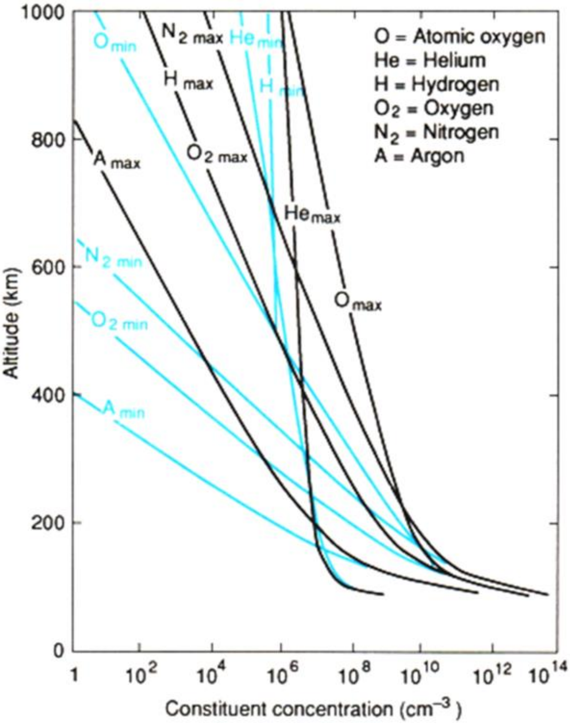


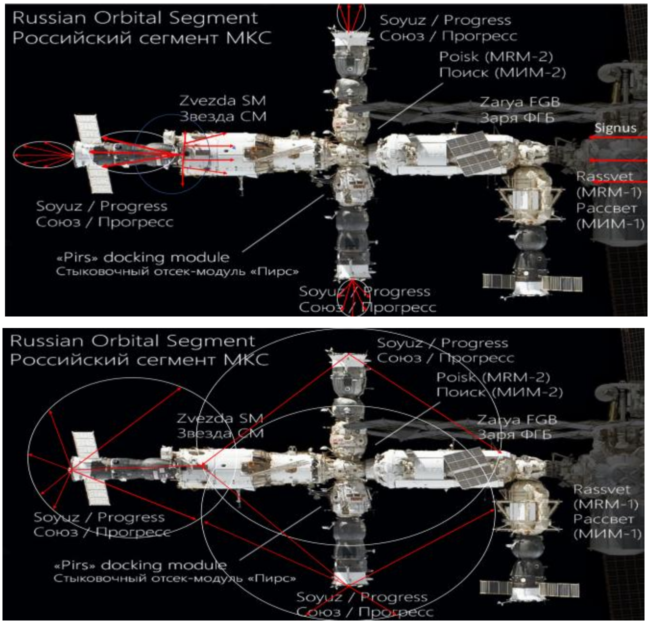
Fig. 9. Concentration of the components of the space environment at altitudes from 100 to 1000 km

As noted, the fuel used is unsymmetrical dimethylhydrazine ADMH, codenamed “heptyl”, which is a high-boiling component of rocket fuel (boiling point above 0°C). Nitrogen tetroxide (AT) is used as an oxidizer of ADMH, either pure or in a mixture with nitric acid. Cases using pure acid and liquid oxygen are known. It can be used in a mixture with hydrazine, known as aerosine [9,11] to improve its properties. It self-ignites upon contact with nitric acid and dinitrogen tetroxide-based oxidizers, which simplifies construction and provides easy starting and re-engagement of rocket engines. ADMH is thermally stable up to +350°C.

In the range from +350 to +1000°C, dimethylhydrazine decomposes into ammonia, amines, hydrocyanic acid, hydrogen, nitrogen, methane, ethane, resinous, and other substances. At increased temperature, it decomposes into nitrogen and hydrocarbons with the release of heat, an increase in the volume, and the creation of jet force from the nozzles.

Taking into account that the impact process on the surface of the spacecraft takes place even with very small amounts of atoms of the elements at different altitudes of the trajectory of the spacecraft (Fig. 9), (well systematized and summarized in [12], where cited and the results of the team from SRTI–BAS [2,13]), we can conclude that in the given case there are far more intense impact processes taking place, albeit short-lived, as a result of the spread of gases from the engines.

The gas jets coming out of the engines' nozzles spread almost instantaneously in the three-dimensional space, which is determined by the practical vacuum around the station (Fig. 10). Depending on the spatial position of the station and the direction of the change in the speed of the ISS, as well as from the engines that are used, the studied samples are subjected to an impact, causing processes (oxidation) on their surfaces.

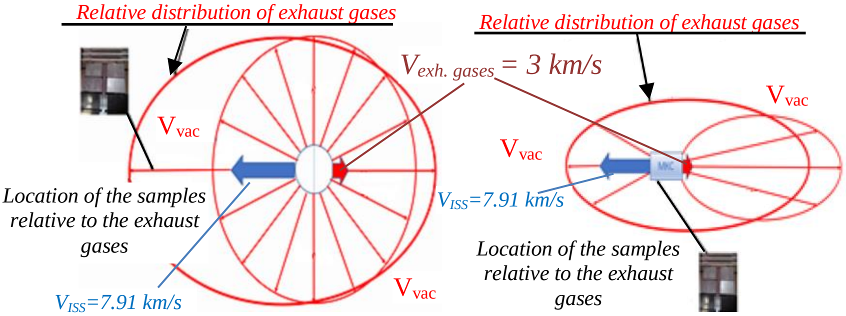


a)

b)

Fig. 10. Propagation of the gas jets from the engine nozzles in the three-dimensional space around the ISS [14]

In fact, contrary to the initial impression that the gases from the exhaust gases from the engine nozzles always remain behind the board of the ISS, thanks to their relative motion, they spread partially on the surface of the station, which is also the reason for the condition of the surfaces of the examined samples (Fig. 11).



a) b)

Fig. 11. Different flow of the samples, depending on the position of the motors used for correction

Conclusion

It can be assumed that the minimal changes on the surface of GC samples, “front”, is due precisely to the large amount of fuel used during the experiment, which turned into gases from the nozzles of the engines of the ships Progress, Soyuz and Cygnus during their docking (undocking) and correction and control of the Zvezda module in ISS orbit. These assumptions are also confirmed by the conducted physico-chemical studies of the surfaces of GC samples (respectively “front” – “backside”). Differences are observed between the “front” and “back-side” glassy carbon coating. Thinning in the glassy carbon “front” coating layer is due to the different impact and oxidation conditions from the gas jets determined by their location.

Acknowledgments: This work is financially supported by the Bulgarian National Science Fund under Project KP-06-H27/2, 08.12.2018.

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ВЛИЯНИЕ НА РАБОТАТА НА ДВИГАТЕЛИТЕ НА КОСМИЧЕСКИТЕ КОРАБИ И НА МКС ВЪРХУ ОПИТНИТЕ ОБРАЗЦИ ОТ РАЗЛИЧНИ МАТЕРИАЛИ, МОНТИРАНИ ВЪРХУ ВЪНШНАТА ПОВЪРХНОСТ НА МОДУЛА „ЗВЕЗДА“

П. Гецов, А. Бузекова-Пенкова, Н. Загорски, Г. Мардиросян, Д. Зафиров

Резюме

В работата е представено изследване на влиянието на двигателите на космическите кораби и Международната космическа станция при корекция на височината на орбитата на станцията. Определени са зоните на действие на газовите струи и тяхното въздействие на околната среда и повърхностите на експерименталните образци от различни материали, монтирани на външната страна на модула „Звезда“.