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# From the R-7 Missile and the First Manned Mission into Space up to Permanently Manned Orbital Station[1]

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**Abstract**—The paper presents a brief history of preparation for, and execution of, the first manned mission on Vostok spacecraft. The key tasks and challenges met to make this historical event possible are discussed. Further achievements of Russian manned space missions are presented, including the world's first orbital station Salyut built and launched in orbit 50 years ago. The role of people in space mission is studied. The in-orbit challenges are discussed, as well as their solutions that were found by the crews and improved the spacecraft safety and performance. Examples of crew operations during the missions of the Salyut orbital stations, Mir orbital facility, and the International Space Station are given to illustrate such challenges. The importance of cosmonauts' participation in the research and experiments on the orbital stations is demonstrated, and positive examples of such participation are provided.

**Keywords:** space mission, launch vehicle, orbital station

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## INTRODUCTION

The progress in the Russian cosmonautics was largely due to the development of the famous military missile R-7 [1]. It made it possible to launch the first artificial satellite of the Earth into orbit, implement the first flight of a human into outer space, take a photo of the far side of the Moon, and achieve many other goals [1–5].

R-7 was a two-stage ballistic missile. Its key purpose was to deliver nuclear charge to any point in the territory of a potential enemy. Preliminary theoretical developments for this missile started in 1950. In 1953, pursuant to the governmental decree of February 13, 1953, the experimental design bureau OKB-1 (now RSC Energia) started the project of a long-range (8000 km) two-stage ballistic missile weighting up to 170 tons, with a detachable warhead weighting 3000 kg in mass. In October 1953, the technical specifications were changed: the mass of the fire charge was increased up to 3000 kg, and the mass of the missile warhead up to 5500 kg, with the flight range remaining unchanged. This new requirement proved to be excessive from the military point of view; however, it formed the basis for the development of Russian manned cosmonautics.

In February 1954, the main milestones of the missile design were approved, and on May 20, 1954, the decree on the development of the two-stage ballistic missile R-7 (8K71) was issued. According to that document, OKB-1 of the research institute NII-88 was appointed as the main designer, and its associate contractors were OKB-456 (engines), NII-885 (control system), Spetsmash (ground facilities), NII-10 (gyro devices), KB-11 (special charge), and NII-4 of the Ministry of Defense (field tests) [1].

## DEVELOPMENT OF R-7 MISSILE. LAUNCH OF THE WORLD'S FIRST MAN-MADE SATELLITE OF THE EARTH

At that time, neither the USSR nor other countries had any experience in creating two-stage missiles. The R-7 missile was a product of creative approach to the most challenging tasks in the new technology.

The concept design for the R-7 missile project was completed in July 1954. The structure of the R-7 missile was fundamentally different from all the previously developed missiles in the configuration and structural arrangement, dimensions and mass, propulsion capacity, the number of systems, etc. It consisted of four identical strap-on boosters attached to the core stage. In terms of the interior configuration, the strap-on boosters and the core stage were similar to those in single-stage missiles with the oxidizer tank located

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frontally. The fuel tanks of all the stages were integral. The engines of all five stages were ignited on the ground. When the stages separated, the side engines were cut off, and the core stage continued flying.

The concept design was reviewed by a special Board of Experts which was headed by Academician M.V. Keldysh and included some prominent researchers and professionals. The Board approved the design of R-7 missile; on November 20, 1954, it was finally approved by the Council of Ministers of the USSR, and on March 11, 1955, it was approved by S.P. Korolev.

As early as in March 1957, the first R-7 missile was delivered to the pre-launch processing site for flight tests, and its first launch took place on May 15, 1957. The missile flight was normal until the 60th second, and then some changes in the engine exhaust gas from the aft compartment became apparent; on the 98th second of the flight, the strap-on booster D fell off, and the missile lost stability. The accident was caused by the propellant line leak. The second launch was scheduled on June 11, 1957. Three trials were made and all of them failed, after which the missile was removed from the launch pad and returned to the pre-launch processing area. The third launch was carried out on July, 12, 1957. On the 33rd second of the flight, the missile lost stability due to the pilot circuit short to the hull. The forth launch of the missile on August 21, 1957 was successful, and for the first time the missile reached its destination on the Kamchatka Peninsula.

In the second half of 1956, it was decided to involve Kuibyshev Aircraft Plant No. 1 in the series production of the R-7 missile. Sergey Korolev sent D.I. Kozlov, the lead designer of the missile to the city of Kuibyshev (now Samara) to organize the production process. The leading enterprises of Kuibyshev city and region were involved in creating the missile, and later the missile and space technology. Thus, Kuibyshev-Samara became the largest center of the missile and space industry in the USSR and later in Russia.

The flight tests of the missiles continued. From December 24, 1958 until November 27, 1959, sixteen missiles were tested, eight of which were mass-produced by Kuibyshev Progress plant.

In accordance with the decree of January 20, 1960, the intercontinental ballistic missile R-7 (8K71) was put into the Soviet Army service.

While working on the R-7 missile, S.P. Korolev always kept in mind the idea of practical and scientific exploration of space. The R-7 missile made his dreams come true.

On March 16, 1954, Academician M.V. Keldysh held a meeting where the research problems solved using artificial Earth satellites (AES) were defined.

On May 27, 1954, S.P. Korolev submitted a proposal to the Minister of Defense Industry D.F. Ustinov to develop an AES, presented in memorandum "On Artificial Earth Satellite" prepared by the research supervisor M.K. Tikhonravov.

In August 1954, the Council of Ministers of the USSR approved the proposals related to the space flight objectives. A decree regarding the AES project was issued on January 30, 1956. According to this decree, in 1956–1958 an unorientated AES weighting 1000 to 1400 kg with 200–300 kg of payload (object D) was to be created and launched by a missile of R-7 type.

In the same decree, the USSR Academy of Sciences was charged with general science lead function and procurement of equipment for investigations; and the Ministry of Defense Industry was to create the AES functioning as a carrier of research equipment. The main contractor for the AES development was OKB-1, and by June 1956, the concept design was complete. Associated designs were also developed by cooperating enterprises responsible for the control system, launch facility, etc.

The research equipment on the satellite D was intended for measuring the atmosphere density and ion composition, the corpuscular emissions from the Sun, the magnetic fields; studying the cosmic rays, etc.

By the end of 1956, it became clear that the satellite and research equipment would not be finalized within the schedule. For this reason, OKB-1 proposed to launch a simple satellite up to 100 kg in April or May 1957. On February 15, 1957, a resolution was issued to launch a simple unorientated satellite (object PS) into orbit to check the possibility to observe the PS in the orbital flight and to receive its RF signals.

A launch vehicle 8K71PS No. M1-PS with the first AES was launched on October 4, 1957, at 10.20 p.m. (Moscow time). It was the fifth launch of R-7 missile. The satellite that was launched in the orbit is shown in Fig. 1. The second stage of the missile with the satellite reached the orbit with a perigee of 228 km, an apogee of 947 km, and an orbital period of 96.2 minutes.

The launch of the first AES was an unexpected event for other countries. All mass media in the world wrote about that.

The launch vehicle with the second AES was launched on November 3, 1957; the mission was organized and prepared for in less than one month as directed by the Government on the event of the 40th anniversary of the Great October Revolution. For the first time, a living creature, a dog called Laika, flew aboard the AES.

On May 15, 1958, a modified launch vehicle RN8A91 No. B1-215 was launched successfully, and the third, now research AES weighting 1327 kg reached the orbit and lasted until April 6, 1960, i.e. for 692 days.

The next step was the flights of spacecraft Luna-1, Luna-2, and Luna-3 to the Moon. Luna-2 delivered a banner of the USSR onto the Moon surface on September 14, 1959, and Luna-3 was the first to take photos of the reverse side of the Moon in October 1960. These were great successes of S.P. Korolev and his famous enterprise in Podlipki [2–5].

After that, a satellite Zenit-2 for photographing the Earth surface and a satellite Elektron for studying the near-Earth space were built.

A human flight was not far off.

## VOSTOK SPACECRAFT AND THE FIRST MANNED FLIGHTS IN ORBIT

OKB-1 started developing a manned spacecraft in spring 1957 at a specially created design department no. 9 headed by M.K. Tikhonravov. The structure of the manned spacecraft was based on the R-7 missile. Studies were carried out at OKB-1 from September 1957 to January 1958.

As a result, the following conclusions were drawn [1]:

• using a modified three-stage missile, a spacecraft with a mass of 4.5 to 5.5 tons, accommodating a person and all necessary service and research equipment, can be launched into AES orbit;

• for the first human flights, it is advisable to use a ballistic trajectory plan of descent from orbit;

• when a spacecraft is descending from orbit, the temperature of its surface reaches 2500–3500°C, and the maximum axial g-load reaches 8–9, which is acceptable if acting in the chest to back direction;

• exposure to high temperatures requires thermal protection the mass of which will be 1300 to 1500 kg;

• for the first flights, it is advisable to choose a circular orbit with the minimum permissible altitude of 250 km;

• the descent module with a human should have a spherical shape;

• during the flight, a person can stay in a descent module;

• safe landing of the pilot is provided by programmable ejection at an altitude of 8–10 km;

• the spacecraft should have an attitude and motion control system with the rotating masses and reactive forces being used as actuating elements (the propellant is compressed gas);

• systems for the orbit monitoring and for commands transmission from the ground control stations are required, as well as two-way radiotelephone communication;

• it is advisable to place the equipment for orbital flight and the retropackage in a separate compartment;

• to ensure reliability, it is necessary to conduct experimental tests of the spacecraft systems on testbenches, and drop tests of the ejection and landing systems on aircraft and during the launches of R-2 or R-5 missiles.

**Fig. 1.** Pre-launch processing of the first man-made Earth satellite.

In autumn 1958, the development of design documentation began, as well as the issuance of technical specifications for building the spacecraft onboard systems.

On May 22, 1959, the Government issued a decree which set a task to develop an experimental version of an orbital spacecraft. It was planned to use it as a basis for developing a reconnaissance satellite and a spacecraft for human flight. OKB-1 was specified as the main contractor for the spacecraft development. A series of subsequent resolutions of the Government specified the tasks and the deadlines for the first manned spacecraft construction.

According to the governmental decree of October 11, 1960, Vostok spacecraft with a man onboard was to be launched in December 1960.

The spacecraft Vostok consisted of a descent module of 2.4 tons in mass, and an instrument module of 2.3 tons, where a retropackage with an engine (thrust) was located. At the end of the orbital flight, the descent module returned to the Earth. The cosmonaut in the descent module was wearing a spacesuit which could sustain the cosmonaut for 4 hours in case of the cockpit depressurization. The spacesuit also protected the cosmonaut in case of ejection from the pressure cockpit at an altitude of 10 km.

It was essential to achieve reliable attitude control of the spacecraft before deorbit burn, because any error in the spacecraft attitude would make the descent impossible. The control system of Vostok spacecraft was developed under the management of Deputy Chief Designer B.E. Chertok at the department 27 headed by B.V. Raushenbakh [6]. The attitude control system had two independent modes: automated and manual. Two identical sets of fine thrusters (eight ones in each) working on compressed nitrogen, were used as actuators; the stock of nitrogen was 10 kg. The auto-

**Fig. 2.** Launch of Vostok spacecraft with Yuri Gagarin onboard.

mated attitude control system comprised the solar and angular rate sensors, and a computing unit. The angular rate sensors were single-axis floated gyroscopes with mechanical feedback. The manual control circuit comprised an optical device for visual observations, angular rate sensors, an attitude control handle, and a logic unit forming the control signals. Direct observation of the Earth surface through the center of the screen of the optical device (orientation device Vzor) made it possible to control the flight direction.

The launch of a spacecraft with test animals on July 28, 1960 failed because of the launch vehicle accident. The launch of test animals with their successful return took place on August 19, 1960. On August 20, the dogs Belka and Strelka returned back to the Earth. During the launch on December 1, 1960, there was a failure of retropropulsion system and descent in a wrong area. The descent module with the dogs Pchelka and Mushka had to be blown up. During another launch on December 22, 1960, the launch vehicle accident happened. The descent module separated in an emergency mode and landed successfully after suborbital flight. When the descent module was descending, the ejection device failed, and this saved the lives of the dogs Kometa and Shutka who stayed within the descent module in the freezing cold after emergency landing in an off-target location.

In late 1960 and early 1961, a series of spacecraft 3KA were constructed for flight testing in unmanned mode. Since the retropropulsion system was the only one that was not redundant onboard, these functions were additionally ensured by natural deceleration of spacecraft in the atmosphere. The spacecraft life period could reach 10 days due to proper selection of the perigee altitude.

Spacecraft 3KA No. 1 was launched on March 9, 1961. It was equipped with all onboard systems. There were also a dog called Chernushka and an anthropomorphic dummy there. The mission program was fully completed, the equipment operated flawlessly; the descent module with the dog landed successfully, and the dummy was ejected nominally. The launch of spacecraft 3KA No. 2 with the dog Zvezdochka onboard was also successful.

The flight tests of the manned spacecraft Vostok were finished. To summarize the results, it should be noted that 46 launches of the launch vehicles R-7 (1st and 2nd stages of the missile 8K71) and 16 launches of the block E (3rd stage) of the launch vehicles 8K72 were carried out at this phase. Six of the 16 blocks E did not come into action because of accidents on the launch vehicles, and two blocks failed themselves. Two of the seven Vostok spacecraft (1K and 3KA) did not reach orbit because of the launch vehicles destruction in an active section of the trajectory; and two spacecraft did not fully complete the flight mission.

The flight tests also showed that after the fourth pass of the orbit, the dogs onboard the Vostok spacecraft experienced some physiological changes. This made it necessary to plan the first human flight lasting for only one orbit pass, and to automate the spacecraft control as much as possible.

The program of manned space flights by Vostok spacecraft, adopted by the State Committee, provided for the launch of six spacecraft, including two group flights with two spacecraft in each. The first female cosmonaut was also preparing for space flight.

The Vostok spacecraft with the first cosmonaut Yuri Gagarin was launched on April 12, 1961, at 9 h 06 min 59.7 s a.m. (Fig. 2). The spacecraft weighting 4725 kg was set into orbit by a launch vehicle 8K72 with a lift-off weight of 287 tons. The orbit perigee was 181 km and the apogee was 327 km. Later, the launch vehicle 8K72 was also called Vostok. The launch was led by S.P. Korolev, A.S. Kirillov, and L.A. Voskresenskii. The flight of the first cosmonaut lasted for 108 minutes. Yuri Gagarin landed in Saratov region near the bank of the Volga river. It was an outstanding achievement which started the era of human flights in space. Since then the 12th of April has been celebrated annually as the Cosmonautics Day.

As is known, due to off-nominal shutdown of the engines of the launch vehicle second stage, Vostok spacecraft entered the orbit with an apogee exceeding the designed value by more than 110 km [7]. It was a serious incident, because in the event of the retropropulsion system failure, natural descent from such a high orbit would be too long. If the spacecraft was launched nominally, the time of its existence in the orbit was up to 10 days, so the cosmonaut could stay onboard until landing. The time of Vostok spacecraft existence in the actual orbit was 22 days, which meant that Gagarin would have been doomed if the retropropulsion system had failed [7].

After Vostok spacecraft left the Earth's shadow and the required attitude was established, the retropropulsion system was switched on. The retrograde deorbit burn was performed with some flaw, which affected the actual landing point of Yuri Gagarin near Smelovka village in Saratov region, in 5 km from the left bank of the Volga. According to calculations [7], if the deorbit burn value had happened to be 0.43 m/s higher, Gagarin would have landed in the middle of the Volga river which is quite wide in this location, and this would have made his rescue much more difficult [7].

On August 6, 1961, the spacecraft Vostok-2 with cosmonaut G.S. Titov was launched. The flight lasted for 25 hours and was completed successfully. A modified professional film camera Konvas was installed on Vostok-2 to take video of the Earth through a viewport.

One year later, simultaneous flight of two manned spacecraft was implemented. On August 11, 1962, Vostok-3 spacecraft with A.G. Nikolaev was launched, and on the next day it was Vostok-4 with P.R. Popovich. The orbital flight of Vostok-3 spacecraft lasted for 94 hours, and that of Vostok-4 was 71 hour.

The next group flight was carried out in June 1963. The Vostok-5 spacecraft with V.F. Bykovsky was launched on June, 14, and Vostok-6 with the first female cosmonaut V.V. Tereshkova—on June, 16. Their flights lasted for 120 and 72 hours, respectively.

The flights of manned spacecraft resulted in the development of a service for detection, maintenance and evacuation of spacecraft and their parts, as well as cosmonauts from the landing sites.

The experience gained during the Vostok spacecraft construction was used in the projects of a three-person spacecraft Voskhod (3KV) and a two-person spacecraft Voskhod-2 (3KD), but with some modifications. For instance, the crew did not wear spacesuits in the descent module; and a new landing system was developed, which did not require the crew ejection.

On October 12, 1964, the three-person manned spacecraft 3KV was launched, which was called Voskhod (Sunrise) in the mass media. Its flight with cosmonauts V.M. Komarov, K.P. Feoktistov, and B.B. Egorov lasted for 24 hours and was completed successfully. It was the first trial of a multiperson spacecraft.

The next step was extravehicular activity from Voskhod-2 spacecraft. The design of the spacecraft was modified to ensure a cosmonaut's spacewalk: an airlocking system was introduced; the third prone bed was removed, and in the two remaining ones the cosmonauts had to wear spacesuits. The airlock for spacewalking was inflatable; it was installed on one of the hatches of the descent module. A manhole with a diameter of 700 mm was made in the hatch cover. The outer diameter of the airlock was 1200 mm, the inner diameter was 1000 mm, the height was 2500 mm when unfolded and 770 mm when folded; and its weight was 250 kg.

**Fig. 3.** Sergey Korolev at Baikonur space base.

The Voskhod-2 spacecraft with P.I. Belyaev and A.A. Leonov was launched on March 18, 1965. During this flight, A.A. Leonov was the first in the world to enter the outer space and stayed there for 12 minutes. The whole flight of Voskhod-2 lasted for 26 hours. When descending, the automated attitude control system failed, so the crew had to manually set the attitude required for descend and start the retropropulsion system. The descent module landed in an unscheduled location, in a forest in Perm region; that is why the cosmonauts were evacuated from the landing site only on the third day.

The country's success in space exploration was to a great extent due to Sergey Korolev (Fig. 3). On January 14, 1966, this country and OKB-1 lost their chief designer: S.P. Korolev died during a surgery.

When analyzing the reasons for the success of Korolev's lifework, it should be noted that he was a combination of a talented, or even brilliant engineer and manager. He had deep understanding of difficult technical problems and was able to find excellent solutions to them. Korolev was also a good recruiter; a lot of talented specialists worked for OKB-1. In those years, there was a system of young specialists placement to jobs, which made it possible to send the best graduates from the best universities to OKB-1. Nevertheless, in 1959 Korolev organized the department of electronics and system engineering at Moscow Institute of Forestry near OKB-1, the famous FEST (now the Space Department of Mytishchi Branch of Bauman Moscow State Technical University), as well as the department of missile and space engineering in Podlipki. Today these departments provide most of young specialists for RSC Energia. Thanks to his credibility, Korolev could contact directly the country's government officials to solve both technical and social problems. When managed by Korolev, life in Podlipki changed: many employees got modern apartments.

Korolev's ideas had a nationwide scale; many achievements of OKB-1 were further developed by other enterprises. For instance, the production of R-7 missile and the Earth observation satellites was transferred to Samara, communication satellites—to Krasnoyarsk, and satellites for deep space exploration—to Lavochkin Research and Production Association. When S.P. Korolev died, the situation began to worsen. As B.V. Raushenbakh wrote later, "the commander was gone, and the army became weaker."

On March 6, 1966, by the Order of the Minister of General Engineering, OKB-1 was renamed the Central Design Bureau of Experimental Mechanical Engineering (TsKBEM), and the experimental plant no. 88 became the Plant of Experimental Mechanical Engineering. The TsKBEM was headed by V.P. Mishin who was appointed to the position of the Chief Designer after S.P. Korolev's death.

## SOYUZ SPACECRAFT AND MANNED ORBITAL STATIONS

The TsKBEM continued the works started under S.P. Korolev. The development of the transport spacecraft Soyuz and a long-term orbital station Salyut are worth special attention.

In contrast to Vostok, the manned spacecraft Soyuz were designed for particular purposes. In 1960, along with Vostok spacecraft, the Department 9 of OKB-1, headed by M.K. Tikhonravov, studied other versions of manned spacecraft, e.g., for flying around the Moon, which required in-orbit assembly and, correspondingly, the development of rendezvous and docking equipment.

The problem of spacecraft rendezvous in orbit was studied by Department 27 headed by B.V. Raushenbakh [8]. The rendezvous procedure was divided into two segments: far and near approach. For far approach, the method of free trajectories was used, where the most fuel-saving trajectory was selected based on the expected motion. Since there were no onboard computers at that time, it was impossible to use this method for near approach. Therefore, a method of parallel rendezvous was developed, where the line of sight (the line of the passive spacecraft observation from the active one) moves translationally [9]. In addition, it was necessary to measure the parameters of relative motion. Several solutions to this problem were considered. Preference was given to the radio system Igla developed in accordance with the technical specifications issued by OKB-1 in 1963. To control the rendezvous process, Department 27 developed a logical command device, a rendezvous control unit.

Studies of the methods and means of spacecraft rendezvous, carried out at OKB-1 made it possible to perform experimental docking of Soyuz spacecraft (7K-OK), and formed a fundamental basis for solving such problems for many years in the future. Scientific, engineering and design investigations to find and select the main engineering solutions for the spacecraft Soyuz were carried out in 1960–1963. As a result, the following required characteristics of Soyuz spacecraft (7K) were determined [1]:

- accommodation of a crew of two people in comfortable flight conditions, which can be ensured by a habitation module introduced in the 7K structure;
- inclusion of automated rendezvous and docking systems in the spacecraft design, as well as manual rendezvous controls;
- improvement of spacecraft onboard systems according to the flight mission;
- possibility to enter the atmosphere at the first and second cosmic velocity, and ensuring controlled descent with lower overloads due to aerodynamic fineness;
- landing of descent module with cosmonauts by means of a missile-assisted parachute system with a redundant parachute system;
- possibility for the descent module to break off the launch vehicle in case of emergency, using solid missile motors.

In 1963, while working on Voskhod spacecraft, S.P. Korolev asked his team to study the possibility for a three-person spacecraft 7K to be used for orbital flights as well.

New onboard systems were developed for Soyuz spacecraft. At the same time, much attention was paid to flight reliability and safety. The essential principle was that a single failure of any system must not lead to hazardous consequences. For this reason, duplication and redundancy were used.

The attitude and motion control system (AMCS) supported the following operations:

- spacecraft attitude control in the inertial and orbital coordinate frames;
- orbital maneuvering;
- rendezvous and docking of spacecraft;
- orientation of solar panels towards the Sun.

The AMCS sensors were two-degree gyroscopes, angular rate sensors, accelerometers, infrared sensor of the Earth vertical, as well as stellar, solar and ion sensors. The parameters of spacecraft relative motion were measured by Igla radio system.

The Soyuz spacecraft design was completely developed in 1965. The spacecraft 7K-OK was intended for a crew of three people and was constructed in "active" and "passive" versions to ensure docking of two manned vehicles. There was a possibility for the crew to move from one spacecraft to the other one via the outer space. For this purpose, Soyuz was equipped with airlocking and spacewalk means including special spacesuits for the outer space. At the same time, the flight spacesuits protecting the cosmonauts in case of inhabited compartments depressurization were not provided.

The spacecraft 7K-OK had the following performance specifications [1]:

- lift-off weight: 6460–6560 kg;
- descent module weight: ~2800 kg;
- number of crew members: 1–3 people;
- spacecraft length: 7.6 m;
- diameter of inhabited modules: 2.2 m;
- maximum diameter: 2.72 m;
- service life in orbit: 3–10 days;
- free volume of inhabited modules: 6.5 $m^3$.

Since it was believed that there should not be a large time interval between the manned flights after successful launches of Vostok and Voskhod spacecraft, the production of the first Soyuz spacecraft and their preparation for the launch scheduled in 1966 were accelerated.

Manned Soyuz-1 with cosmonaut V.M. Komarov was launched before the May Day holiday, on April 23, 1967. After the spacecraft got in orbit, some failures happened: one of the two solar panels did not deploy; the solar and stellar orientation sensor scarcely worked, so the stellar panel had to be oriented to the Sun manually. At that time, preparations for the second spacecraft launch with three people were in progress in Baikonur. It was planned that the two spacecraft would dock in orbit, but the launch of the second spacecraft was canceled because of the failures on Soyuz-1, and the latter was deorbited ahead of schedule.

On the day of Soyuz-1 landing on April 24, 1967, communication between the crew and the Air Force Rescue Service suddenly interrupted. A few hours later, it became known that there was a disaster and V.M. Komarov died during landing.

In course of the accident investigation, the commission found that the tragedy happened because the main parachute failed to deploy from its container. The reason was that the main parachute unit was squeezed by the container walls due to the pressure drop: one atmosphere within the spacecraft and lower pressure in the container at the activation altitude (during the previous flight, there was no such pressure drop because the descent module burnt through and got depressurized!). As a result, the brake parachute connected to the main one had too little force to pull it out of the container.

After a long break of manned flights, G.T. Beregovoy got off the pad on Soyuz-3 spacecraft on October 26, 1968. Docking with unmanned Soyuz-2 was planned, but this could not be done with manual control of the spacecraft from a distance of 200 m. Spacecraft docking was successfully fulfilled during the flight of Soyuz-4 (V.A. Shatalov) and Soyuz-5 (B.V. Volynov, A.S. Eliseev, and E.V. Khrunov) on January 14–18, 1969.

Since 1970, a new main area of work at RSC Energia was the development of manned orbital stations. Thanks to this development in the outer space exploration, our country has achieved the greatest success recognized all over the world. The experience gained in the development and long-term operation of the orbital stations formed the basis for cooperation between Russia and many countries holding the leadership in the space industry, including the United States.

In 1960-s, RSC Energia (TsKBEM at that time) was the country's monopolist in manned flight programs. At the same time, the Central Design Bureau of Mechanical Engineering (TsKBM) headed by V.N. Chelomei was building a manned orbital complex Almaz, while in the US the development of Skylab orbital station was in active progress [1]. Since TsKBM had no experience in building the manned spacecraft similar to Soyuz and Vostok, the Government instructed TsKBEM to construct a long-term orbital station (LOS). Related resolution on the development of the station DOS-7K was issued on February 9, 1970. This made it possible to construct the world's first manned LOS within a short time and to ensure the country's headship in this area of space exploration [1, 10].

LOS No. 1 was called Salyut (Salute) and launched into orbit on the launch vehicle UR-500K Proton on April 19, 1971 [1, 10]. The first expedition to the station on the spacecraft Soyuz-10 with the crew of V.A. Shatalov, A.S. Eliseev and N.N. Rukavishnikov was launched from Baikonur space base on April 23, 1971. The spacecraft failed to dock to the station because of some problems with the docking mechanism. The second expedition of G.T. Dobrovol'skii, V.N. Volkov and V.I. Patsaev on the spacecraft Soyuz-11 was launched into orbit on June 6, 1971, and after successful docking on June 7, the LOS Salyut started functioning as the first manned research station. The crew worked in orbit for about 23 days, which was a record for humans working in space conditions. The flight program included a number of scientific and technical experiments relating to star mapping using a UV telescope Orion; studying the World Ocean in the interests of fisheries; medical research, etc. On June 30, Soyuz-11 spacecraft was undocked from the station and landed, but this landing was disastrous: the cosmonauts died [1, 10]. After that, until October 11, 1971, the station operated in automatic mode, although the plan was to stay in orbit for three months. The next station of this type was launched on July 29, 1972, but it failed to reach its expected orbit because of the launch vehicle Proton accident.

Simultaneously with the construction of Salyut station, TsKBEM worked on its improvement, and already in 1970 an orbital station of the second generation was completed. It was designed with three solar panels (instead of two ones), each of which could rotate about its longitudinal axis. The guaranteed service life of the station in orbit was increased twice and amounted to 180 days.

The first station from the DOS series of the second generation was DOS No. 3 (Kosmos-557). It was launched into orbit on May 11, 1973; however, due to improper operation of the ion sensor in the system of motion control in the flight segment outside the zone of radio visibility from the USSR territory, the station fully ran out of fuel and became uncontrollable in terms of attitude, so it could not function nominally in orbit. Correction to the orbital height could not be done, and in May 1973 the station ceased to exist.

Along with the LOS missions, TsKBM implemented the program of Almaz stations for the Ministry of Defense; in the mass media, these stations were called Salyut-2, 3 and 5.

LOS Salyut-4 developed by TsKBEM was launched into orbit on December 26, 1974. Its design was similar to LOS No. 3. The first expedition to Salyut-4 station was carried out by cosmonauts A.A. Gubarev and G.M. Grechko who worked in orbit from January 11 until February 9, 1975. The second expedition (P.I. Klimuk and V.I. Sevast'yanov) lasted for 63 days, from May 24 until July 26, 1975. This record-breaking flight coincided with the first Soviet-American flight under Soyuz-Apollo Program.

The first experience of in-situ management of space experiments was also gained during Salyut-4 mission. There was the latest research equipment at the station: an X-ray telescope/spectrometer Filin, a reflector X-ray telescope RT-4, an infrared telescope/spectrometer ITS-K and other research instruments. To fulfill the flight mission and conduct the experiments, Salyut stations were equipped with AMCS designed under the supervision of future academicians B.V. Raushenbakh and B.E. Chertok. The AMCS provided automated and manual attitude control of the station in the orbital coordinate frame, as well as rotation and orientation of the station's axes to specific points of the celestial sphere. In order to set the research equipment to particular objects, it was necessary to set the initial (orbital) attitude, then, at a particular time point, switch the station in the inertial orientation mode, and perform its programmed rotations until the research equipment is set to the studied objects [5]. Special control settings (the time point for the station transition into inertial orientation mode and the rotation angles) were calculated by the Ballistic Analysis Center of the Ministry of Defense and sent on board.

In the orbital orientation mode, the longitudinal axis ($x$ axis) of the station is oriented with reference to the velocity vector, while the $y$ axis which corresponds to the maximum moment of inertia coincides with the radius vector of the station's orbit. Research equipment for the Earth observation is installed along the station's $-y$ axis, and that for studying the astronomic objects—along its $+y$ axis. Thus, it is possible to observe the objects on the Earth during the flight in the orbital station mode, and to scan the celestial sphere with the equipment installed along the +y axis, using the orbit precession.

The first orbital stations could not be refueled in orbit, so the capabilities for setting the research equipment to the studied objects were quite limited. In order to make these capabilities higher, additional modes of the station passive spinning were proposed, in which the station spinned about its longitudinal axis $x$ oriented in space as required. In this case, the celestial sphere could be scanned with the telescopes installed on the $+y$ axis. The action of gravitational and aerodynamic disturbing torques on the station resulted in the "destruction" of the spin performed. Special methods and appropriate mathematical support were promptly developed to restore the spatial orientation of the telescopes' axes during the celestial sphere scanning modes [11]. Salyut stations of the second generation were equipped with the sensors of the Earth's magnetic field strength and the Sun position for orientation monitoring. During the flight in the orbit segment illuminated by the Sun, the attitude of the station was calculated in situ at the rate of reception of telemetric information based on the solar sensor and magnetometer measurements, using a two-vector algorithm [11]. At the same time, the attitude calculation results were displayed at the Mission Control Center, also at the rate of reception of telemetric information, which was a notable achievement in those years. It was much more difficult to calculate the station attitude in the shadowed part of the orbit where there were no measurements from the solar sensor, because this put limitations on the prompt solution of all problems at the Mission Control Center near the town of Evpatoriya (TsUP-E), where there was a computer M-220 at that time. In order to promptly calculate the station's motion and attitude, using the available computers, it was necessary to develop new methods for describing the perturbed motion of a spacecraft, the integration methods, and the methods and algorithms for attitude calculation [11]. The new integration method accelerated the calculation by more than an order of magnitude. The analytical solution found for the perturbed motion of the station was more accurate and at the same time simpler than the known ones. Fast algorithms were developed for calculating the station's attitude in the shadowed part of orbit for a motion mode close to regular precession [11], and for highly perturbed motion of LOS. These algorithms required the minimum computer RAM because it did not depend on the amount of data calculated and received at a rate of telemetric information [11]. All these things were for the first time implemented at TsUP-E (Fig. 4) during the mission of Salyut-4 LOS.

**Fig. 4.** Mission Control Center for Salyut-1–5 in Evpatoriya (the photo was taken 40 years later, in 2013).

Having learnt the lessons from Salyut-4 LOS flight experience, TsKBEM created the stations of the third generation Salyut-6 and Salyut-7. Their main feature was that they provided for simultaneous presence of two spacecraft Soyuz or one Soyuz and one Progress transport spacecraft at the station. Since there were two docking facilities, there was no need to leave the station in the automatic mode while changing the crew. Progress spacecraft made it possible to deliver consumables, new equipment and fuel to the station, thus increasing its capabilities for research experiments during the mission [1].

It was decided to transfer the Mission Control Center for the third-generation stations Salyut-6 and Salyut-7 to TsUP-M that had been established in the town of Korolev for Soyuz-Apollo Program [12]. Within the main operational management group, a special team was formed to organize and control the experiments. The technology for the experiments and their operational support was developed using the experience of work with Salyut-4 station at TsUP-E in Evpatoriya.

In the course of preparation and implementation of research programs at Salyut stations, a special technology for space experiments was developed for the first time [11, 13], which covered the following tasks:

- planning of experiments;
- experiments program optimization;
- mathematical modeling;
- experiment implementation;
- in-flight monitoring and control of research equipment;
- express analysis of scientific data on telemetric information;
- measurement and calculation of additional information for the analysis and interpretation of the results of space experiments [11, 13–15].

Real-time support of experiments at the stations Salyut-6 and 7 was carried out at TsUP-M and computer center of RSC Energia (Research and Production Association NPO Energia at that time) [1]. Automated monitoring of the research equipment operation and express-analysis of scientific data made it possible to make prompt decisions on the space experiments progress management [11].

When planning the research, possible zones for conducting the experiments are considered, including the time intervals during which all the conditions and restrictions affecting the possibility to conduct them are met [11].

Due to orbit precession, spacecraft motion along the orbit, special motion of the Earth and other factors, the duration of the zones for space experiments changes during the mission. For this reason, it is essential to find optimal (e.g., in terms of duration) zones for conducting the experiments, i.e., to find the best time points for research planning [11, 15]. Such problems were solved successfully, and the results were used during the flights of orbital stations, so the investigations were carried out effectively with limited available resources (fuel, crew's time, etc.).

Thanks to the optimization methods developed, in some cases it became possible to increase the informativity of research program 2 or 3 times compared to the traditional methods of planning, which was demonstrated during long missions of the orbital stations. Moreover, the new planning strategy helped to find the best time intervals (zones) for conducting the experiments.

When planning and implementing the extensive research programs on LOS, it was necessary for the first time to develop a technology for setting the research equipment to the studied objects, taking into consideration limited fuel resources and requirements for setting accuracy. For maintaining the LOS flight in the orbital station mode, or rotating the station about its longitudinal axis, fuel consumption is by an order of magnitude less than, for example, for rotating the LOS about its transverse axis. This circumstance and other factors were kept in mind when developing the technology of research equipment setting to the studied objects [11].

The setting accuracy depended on the errors in the LOS initial attitude, the duration of rotation maneuvers, and other factors. When setting the research equipment to the studied objects, it was important to align this equipment, i.e. to determine mutual position of sensitive axes of the research equipment and the axes of the LOS. Initial alignment of the research equipment and LOS axes was carried out on the ground after the equipment had been installed on the station body. After the station has been put in orbit, due to the pressure difference inside and outside the station, the sensitivity axis of the research equipment shift relative to the LOS axes. The value of such a shift can reach 1° to 1.5°. During the station flight, its surface temperature varies within the range of about ±70°C. This also leads to the misalignment of the research equipment and LOS axes by 20–70 arcmin. As a result, methods for the research equipment in-flight alignment were developed, which ensured more accurate setting of this equipment to the studied objects.

The first station of the third generation LOS No. 5 Salyut-6 was launched into orbit on September 29, 1977. From this date until July 29, 1982, the station was used by 5 main expeditions and 11 visiting expeditions [16].

After that, LOS No. 5-2 (Salyut-7) was launched into orbit on April 19, 1982. The design of Salyut-7 to a great extent repeated that of Salyut-6; however, some improvements were made. For example, one of the serious problems with Salyut-6 was power deficit: there was always lack of power for power-consuming operations. On Salyut-7 there was a possibility to install additional solar panels during flight.

During the flight of Salyut-7, a system of autonomous navigation and control Delta was optimized at the station [17]. Previously, in 1971, Delta system onboard Salyut employed a space sextant and an optical vertical sensor LV-1. The sextant measured the angles between the direction to a star and the Earth horizon, and LV-1 measured the angles between the vertical and typical features on the Earth surface (islands, capes, river separations etc.). However, in spite of rather high accuracies, this technology was not further used because it was necessary to disengage the crew from taking the measurements and give them more time for experiments. The main functional unit of Delta system on Salyut-7 station was an onboard digital computing system (onboard computer hereinafter) which received and processed the information from instruments and sensors, did the computations, and formed the control commands for the station's devices and systems. The navigation instruments within Delta system were an orbital radar altimeter (ORA), a Doppler radial velocity meter, and solar eclipse sensors (SES). The ORA measured the altitude to the Earth surface in response to commands from the onboard computer. The Doppler meter measured the station flight velocity relative to the Earth-based radio beacons.

The SES fixed the time points the station entered the Earth's shadow and left it. The sensor was a photometer configured in such a way as to register the moments of sunrise and sunset, corresponding to the visible position of the Sun at an altitude of about 25 km above the Earth surface. This was done in order to avoid the errors caused by the Earth terrain and clouds. Six SES were installed on the external surface of Salyut-7 station to ensure full spherical view, taking into account shading of the sensors by the station's structural elements.

The modes of navigation measurements at the Salyut-7 station were automated; all measurements and orbit determination operations were carried out by the onboard computer without the crew involvement.

The devices used as the sensitive elements for attitude control at Salyut-7 station were as follows: angular rate sensors (ARS) measuring the components of the station's angular rate relative the axes of the body-fixed coordinate frame; a block of free gyroscopes; an infrared vertical sensor, i.e. an optical electronic sensor of orientation to the Earth center; and a block of accelerometers measuring and integrating the linear accelerations [17]. Visual orientation devices were an optical sighting device OSK-2M which had a central field of sight for determining the attitude by the terrain passed by, and peripheral fields of the Earth horizon observation for determining the attitude by the local vertical; an optical vertical sensor LV-1 with similar central and peripheral fields of sight, which provided higher accuracy of attitude, as well as navigation measurements with the Earth-based reference features by fixing the time points when the reference features crossed special marks in the central field of sight; and a star tracker AO-1, a device for orientation by the starry sky by matching the images of stars with the starry sky image mask [17].

From April 19, 1982 until June 25, 1986, four main expeditions and five visiting expeditions worked at Salyut-7 station.

The experience gained was used in developing the station of the fourth generation, LOS No. 7 (Mir) whose systems were upgraded as follows:

• gyrodynes were used as inertial actuating elements for the station orientations;

• the control system based on the onboard computer significantly expanded the station's capabilities and allowed for reprogramming from the Earth;

• new rendezvous system Kurs did not require any rotations of the station during approach;

• the capacity of power supply system was increased;

• for oxygen supply, a water electrolysis system Elektron and a regenerable carbon dioxide removal system Vozdukh were installed;

• a radio system Antares with a pencil beam antenna was installed for communications via relay satellites.

In spring 1984, the Government of the USSR made a decision to launch Mir station close to the date of the 27th Congress of the Soviet Communist Party.

In the course of work, there were a lot of problems with the station preparation for launch, but all of them were solved. The core module of Mir station was delivered on site on May 6, 1985; however, at that time, simultaneous work on Buran spacecraft preparation was in progress there, which complicated the work seriously.

The first module of Mir station was launched on February 20, 1986. The mission of the orbital station Mir lasted for 15 years and became an outstanding achievement of Soviet cosmonautics. Within this period, 28 resident crews worked at the orbital complex; a large number of experiments were conducted, including those under the international research programs. In fact, the orbital complex Mir was an International Space Station. Its long-lasting mission and unique experiments and investigations were successful due to highly professional work of cosmonauts in orbit [15]. On March 23, 2001, the mission of the orbital complex Mir was finished.

On November 20, 1998, functional cargo block Zarya, the first element of the International Space Station (ISS), was launched into orbit. Russian service module Zvezda was launched and docked to the ISS on July 12–26, 2000 [18].

The crew of the first expedition of the ISS (Yu.P. Gidzenko, S.K. Krikalev, and W. Shepherd) worked in orbit from October 31, 2000 until March 19, 2001. In April 2021, the 65th expedition started working at the ISS.

The crews and various cargos were delivered to the orbital station Mir and ISS by modified spacecraft Soyuz and by transport/cargo spacecraft Progress designed on their basis [19]. The spacecraft were upgraded in order to improve their performance; another reason was that it became difficult to cooperate with some suppliers of components, who happened to become foreign companies after the USSR had collapsed. A large number of modifications were done to the motion control system [19]. The stages of modernization targeted at replacement of analog devices with the onboard computer and modern measuring equipment are described in [20].

For many years, the guidance, navigation and control system (GNCS) of home-produced spacecraft of Soyuz and Progress series has been successfully performing all the tasks envisaged in the design [21], which confirms the fact that the principles accepted as a basis for the GNCS development were absolutely correct. First of all, this regards the basic principle of its construction—the use of a strapdown inertial navigation system [21, 22]. An important step in spacecraft control is also the use of measurements received from a global navigation satellite system (GNSS) [23]. For the first time GNSS was used at the orbital station to support the experiments at the research module Priroda (Nature) of the orbital station Mir [24]. At present, the GNSS receivers developed by Russian manufacturers are widely used in solving various problems of spacecraft and ISS control [21, 23].

## A MAN IN SPACE FLIGHT

The importance of the world's first manned flight in space, which paved the way for other flights, and the results of manned space missions over the 60 years will be still studied for many years in the future. It has been quite a long time that discussions are held on the advantages of manned missions and unmanned vehicles for space exploration: which is more efficient? In this regard, we will try to consider the experience gained, analyze the role of humans in space missions, and conceive some recommendations.

First of all, it should be noted that the desire to fly into space has always been in the human nature. People have always sought to reach new heights, to discover new continents. The motivation to such activities was, in particular, based on the competition between individuals and countries. The rivalry between the USSR and the United States in those years was a good trigger for astronautics development, the launch of the first man-made satellite and the first manned mission. Our country became the winner in the "space race" of those years.

Today, there is no question whether there is a need for manned missions or not, but how to use the achievements of those years properly; it means that the proportions in the development of manned space missions and unmanned spacecraft in Russia need to be determined.

Currently, it is believed that the space programs can be implemented with the maximum efficiency with optimal combination of the automation capabilities and an operator cosmonaut. Therefore, it is essential to determine which functions should be assigned to the cosmonaut. Some conclusions can be drawn from the space programs implemented during the manned missions of Vostok and Soyuz spacecraft and the orbital stations Salyut, Mir and ISS. The functions of cosmonauts onboard a spacecraft consist in maintenance and operation control, and also in conducting the research work and experiments [11].

Spacecraft and orbital stations are controlled automatically in normal flight mode. The cosmonauts are only involved in redundant control modes. For example, the Vostok spacecraft orientation before retroburn for descent was carried out automatically; however, for better safety, starting from the first mission, a possibility has been provided for orienting the spacecraft by means of an optical device [1]. At Salyut stations,

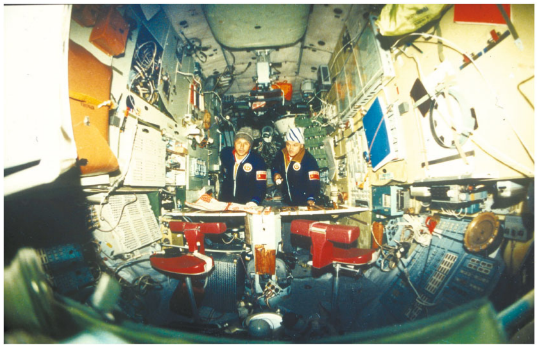

**Fig. 5.** Cosmonauts V.A. Dzhanibekov and V.P. Savinykh at Salyut-7 station.

exact orientation of the station in the inertial coordinate frame was determined using a star tracker AO-1, into which a special "mask" with cut holes ("stars") corresponding to a chosen area of the starry sky was inserted. The cosmonaut manually matched the holes in the mask with the stars. In that case, the accuracy of the station orientation was about 10 arc min.

To improve the reliability of cargo spacecraft Progress docking to the orbital station, the remote piloting mode was additionally introduced, in which the operator at the orbital station could control the motion of Progress spacecraft during rendezvous and docking. Thanks to the remote piloting mode, a lot of emergency situations were avoided when docking Progress spacecraft to the orbital station.

The orbital station maintenance by the cosmonauts consists in scheduled maintenance works, as well as repair in case of equipment failure, incidents and accidents. The role of a cosmonaut in the repair works performed at the station can hardly be overestimated. In many cases, it is the cosmonaut's involvement that made it possible to repair failing equipment and even to save the whole space program. During experiments with the first space radar telescope KRT-10 at Salyut-6 station, the 10-meter-long antenna of the telescope caught on its body elements. The cosmonauts had to undertake unscheduled spacewalk to separate and remove it. Such a complicated task was for the first time fulfilled by cosmonauts V.V. Ryumin and V.A. Lyakhov in August 1979.

A striking example of human indispensability in space orbit is the restoration of operability of Salyut-7 station and actually its salvation in 1985 (Fig. 5).

On February 11, 1985, due to the command control system failure, communication with the station was lost. It was an unmanned part of the flight, so it was impossible to interfere with the automated operation. The battery charging mode of the power supply system was disrupted, the system was deenergized, and the station completely stopped working. There was a real threat of the station loss. The management started searching for a solution in this emergency situation. The main question was whether it was possible to dock to a station that was fully out of control. It was very important to learn its angular rate of rotation. The Salyut stations were equipped with sensors for attitude telemetric control: a magnetometer and a solar sensor. Before losing control, Salyut-7 was in a nonoriented flight mode. Due to this, it was possible to predict the motion of the station for a long time interval, based on telemetric measurements and a mathematical model of its motion relative the center of the mass. It should be noted that the gravitational orientation mode was actively used at Salyut-6 and Salyut-7 stations for a number of experiments [25]; this mode could be implemented in practice due to the long shape of the station structures [26]. It turned out that even in this case, this should have brought the station in the uniaxial gravitational orientation mode [27].

On July 6, 1985, a special expedition of V.A. Dzhanibekov and V.P. Savinykh was sent on Soyuz T-13 spacecraft to Salyut-7 station. By means of target pinpointing from the Earth and manual control using a laser range-finder and onboard computer, the spacecraft Soyuz T-13 approached the station and docked to it. During approach, photos and videos of the station were taken. Subsequent processing of the images confirmed the correctness of the predicted station motion around the center of the mass in terms of its longitudinal axis direction (which module is directed downwards and which one upwards; it was important for docking), and in terms of the maximum values of angular deviations of the longitudinal axis from the local vertical [27].

After successful docking, the cosmonauts carried out repair and restoration works. It was extremely difficult, sometimes even dramatic. For example, among other systems, the temperature control system was out of operation at the station, and the water reserve got frozen, while the volume of water brought on Soyuz was limited. Until the very last moment, no one was sure whether the cosmonauts would manage to warm up the station and use its water reserve, or they would have to return to the Earth without finishing the repair and restoration of the station.

V.A. Dzhanibekov and V.P. Savinykh were a success: Salyut-7 continued its operation.

Similarly, spacewalk of cosmonauts at Mir station helped to eliminate an incident during docking to Kvant module (Fig. 6): a foreign object was removed from the docking port; it obstructed the spacecrafts retraction after docking. The module Kvant was very important for the orbital station, because there was a new attitude control system based on gyrodynes, and a unique research laboratory with X-ray telescopes. After docking and introducing the gyrodynes in the control loop, Mir became the first Russian orbital station that was constantly oriented. This made it possible to continuously set the research equipment to the objects under study. For instance, unique research results were obtained using a system of X-ray telescopes at Mir station [19]. To control Mir orbital station, a special set of mathematical models was developed and used continuously throughout the entire mission [14, 28] to implement an unprecedented program of experiments and investigations [19].

At present, the functions of a cosmonaut during research program implementation onboard a spacecraft are as follows:

• in-flight installation and operation of research equipment;

• conducting experiments in accordance with the methodology of space experiments and onboard instructions;

• participation in selecting the research subjects;

• correction of experiment program/procedure;

• repair and proactive maintenance works.

In order to participate in choosing the research subjects and to correct the program of experiments, the cosmonauts should be educated and skilled appropriately. In this regard, we also note a quite widespread opinion about the need for scientists specializing in particular science areas (astronomers, geophysicists, biologists, etc.) to participate in space missions [11].

The repair and proactive maintenance works performed at the spacecraft can strongly affect the efficiency (and sometimes even the possibility) of the research program implementation. At the same time, it should be noted that the cosmonauts can do the repair and scheduled maintenance work during periodic visits to the spacecraft rather than continuous presence there [11].

Let us consider some examples of cosmonauts' activities during the completed research and experimental programs.

A natural area of research on orbital stations was medical experiments. Our scientists have obtained outstanding results, thanks to which it became possible to carry out long-term manned missions in space orbit [1, 19]. Moreover, the biological experiments and studies with exposing various specimens on the outer surface of the station are also carried out with the cosmonauts' participation; today, only a cosmonaut can install special equipment there and then return it to the Earth. The results of such experiments prove to be extremely valuable [1, 19].

Observation and study of our planet have always been an important part of cosmonauts' activities. Such studies were carried out in almost all manned missions [15, 29, 30] and have been continued on the ISS. The matter is that it is impossible to set the research equipment to the studied objects by rotating the station, because the gyrodynes used for the ISS orientation at the US segment have an insufficient kinematic momentum and can only maintain the orbital attitude of the ISS. To study the Earth's surface within the space experimental program Uragan (Hurricane), the

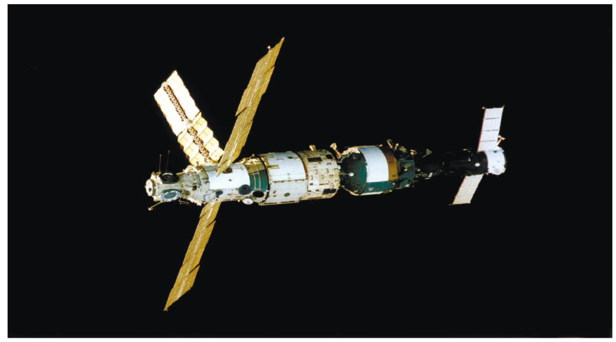

**Fig. 6.** Orbital complex Mir in 1987 (core module, Kvant module and Soyuz-TM spacecraft).

cosmonauts from the Russian segment used manual devices, targeting them at the studied objects through viewports [15, 29, 30].

This year, within the framework of the Uragan space experimental program, a new device called hyperspectrometer was manufactured, and the cosmonauts will take part in the studies and operate this device onboard the station [30].

The capabilities of the orbital station make it possible to periodically deliver new research equipment there and install it on the outer surface. For example, the Icarus equipment created under an Agreement between Roscosmos and DLR and used in the Uragan program was successfully installed by cosmonauts on the Russian segment of the ISS and has already been put in operation [31, 32]. The equipment was delivered to the ISS by two Progress transport cargo ships. At first, Progress MS-07 spacecraft delivered the equipment that was to be installed inside the station's pressure compartment (an onboard computer OBC-I, connection cables and brackets). Cosmonauts A.N. Shkaplerov and O.G. Artem'ev assembled an electrical circuit for connecting the OBC-I to the onboard mains of the service module, and installed brackets for fixing the computer at the workstation. As a result, the cosmonauts opened fifteen panels, laid nine cables the length of which varied from five to seven meters, and installed 27 connectors. The correctness of cabling and the normal functioning of the OBC-I computer were confirmed by three verification tests.

After that, Progress MS-08 spacecraft delivered the Icarus antenna unit to the ISS, as well as equipment specially developed at RSC Energia for its installation: a mast, a Yakor-Icarus device, cable bundles 15 m long each, etc. The airlock compartment (module CO1) from which the cosmonauts astronauts wearing Orlan-M spacesuits go into outer space is 1000 mm in diameter, which allows moving the large-sized items out. The antenna in the transport position, after moving it to CO1, is fit up and acquires a configuration for operation in outer space. With the outfitting equipment

**Fig. 7.** O.G. Artem'ev and S.V. Prokop'ev during Icarus equipment installation.

installed, the Icarus antenna unit can only be moved through this exit hatch.

Spacewalking is an extremely difficult task that is performed by cosmonauts under the guidance of specialists on the Earth. Before leaving, the cosmonauts should prepare thoroughly their spacesuits, the airlock facilities and airlock compartments, service systems, equipment and tools necessary for working in outer space. Preparation of Icarus research equipment consisted in changing the transport position of the antenna unit into the working position, preparing the mast and the Yakor-Icarus anchoring device, as well as winding the cable bundles on the outfitting unit of the multipurpose cable platform (MCP). During the ground preparation for extravehicular activities, specialists from RSC Energia modeled the route of high-frequency cable bundles to be laid. The length of this route was about 15 meters. Especially for the Icarus research equipment installation, the MCP was additionally equipped with a device that allowed the MCP to be attached to the handrails during the spacewalk. Proper winding, laying and fixing of connectors in the MCP is an essential condition for successful installation of cables on the external surface of the station.

During the preparation for the spacewalk, there was also a large amount of work with equipment inside the station. First, the mast and the Yakor-Icarus device designed for the cosmonaut's convenience when performing the installation work were brought to the place of equipment installation. After the mast installation, the cables were laid, and the Yakor-Icarus device was installed on the handrails of the station body using special locks. After that, the cosmonauts took out, installed, deployed and connected the antenna unit of the Icarus equipment (Fig. 7) [32]. Using a large-sized antenna, it is possible to track animals from the ISS orbit by processing the data received from the miniature transceivers (tags) put on the animals [31]. This confirms the fact that the manned station has excellent capabilities for unique studies and experiments. It should be noted that it was the Russian technologies for training the cosmonauts and supporting their activities in outer space that made it possible to successfully perform the extremely complicated work on the installation and deployment of a large-sized antenna in orbit. Currently, Russian and German scientists use the Icarus equipment to receive unique scientific information.

## CONCLUSIONS

Analyzing the current state of Russian and global astronautics, we can make a conclusion that Russia remains one of the world leaders in the field of manned flights. At the same time, it should be noted that the most significant progress in fundamental and applied space science (study of the planets of the solar system, remote sensing of the Earth, satellite navigation, communications, etc.) has been achieved in recent decades with the help of unmanned spacecraft.

The end of our country's rivalry with the United States and the major successes of space projects based on the use of unmanned vehicles make it necessary to develop a strategy for the development of Russian cosmonautics in modern conditions [15]. When developing such a strategy, it is important, first of all, to take into account our country's progress in manned cosmonautics achieved thanks to S.P. Korolev and the talented scientists and specialists involved in these works [1]. The largest space project of our time is the ISS. The role of Russia in this project is really great; today our country has a reliable means of delivering the crew to the station and returning it back to the Earth, provides fuel delivery and maintaining the altitude of the station's orbit. The main task for Russia in the ISS project today is to increase the efficiency of the targeted use of this station, to benefit from participation in this project. This is the way we can hold our ground in this area of space science and exploration, and apply certain expertise and technologies of the ISS project to unmanned vehicles. When solving this extremely important task for the Russian space technology, it is necessary to keep in mind the experience of organization and realization of the largest space projects, such as R-7 missile launch, the launch of the world's first satellite, the first manned missions, construction of the world's first orbital station, etc. The deadlines for some grandiose projects of those years were set in a few months, and this was without modern computing equipment, communications, and with all work carried out in a strictly confidential regime, which certainly complicated the projects.

The effectiveness of scientific and applied experimental programs at a manned station depends on the multi-purpose nature of the work and the presence of a crew. When the research is carried out in different areas, a multi-purpose station can be operated continuously to achieve targeted results [11]. Unfortunately, the capabilities of the ISS for multi-purpose programs implementation are hardly used.

During any research at a manned station, it is still possible to use the capabilities of unmanned spacecraft; what is more, the presence of the crew provides some additional advantages because they can upgrade or reconfigure the equipment, do the repairs, choose proper objects for studies, etc. For example, when observing and studying unusual phenomena including catastrophes on the Earth's surface from an orbital station, there are more chances to select and record additional objects to study. Russian orbital stations have always provided a good opportunity to fulfill the task of the Earth surface surveillance for various consumers, which is quite important for the country's economy. At the same time, the results of most works, such as new surveillance equipment, data collection and transmission systems, the ground segment, the technologies for the received data application, etc. can also be used in the systems based on unmanned spacecraft. Relevant experiments are currently in progress at the ISS [15, 29–33].

In addition, it is essential to further study the activities of cosmonauts in long-term missions and to conduct experiments with their participation. Educational programs for the general population can be recommended as well [15, 29–31, 33].

Generally, it should be noted that to date, thanks to the projects of Mir and ISS stations, manned cosmonautics has been developed in many countries. The future manned programs of the United States and China are aimed mainly at flights to the Moon. It is unlikely that representatives of all the countries developing manned cosmonautics will be able to take part in these missions. Therefore, if Russia develops, builds and launches its own manned station into near-Earth orbit, this will also be a benefit for international cooperation because astronauts from different countries may be invited to participate in this project.

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