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Chapter 17

The Soviet/Russian Spacesuit History: Part II—Space Stations Era, 1970s to 1990s*

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Abstract

After the termination of the Soviet lunar program in the early 1970s, the major direction of the Soviet human space program became the operation of permanent space stations, Salyut, Mir, and International Space Station (ISS). The spacesuit development was to follow two different lines in the 1970s through the 1990s. The space stations required a new suit for several hours of external work (extravehicular activity or EVA), and the transfers of crews to and from the stations were to require a special rescue suit.

For this purpose the experience and results of the lunar spacesuit development were used to create the Orlan spacesuit family, in use in 2003 at the ISS. Starting with Salyut 6 in 1977 all Soviet/Russian space stations have since been permanently equipped with Orlan EVA spacesuits. The first model was Orlan-D, used on Salyut 6 and 7. Until the end of 2002, 208 human EVAs have been performed with the Orlan-family spacesuits. The Orlan suits were designed for permanent stay onboard the stations, and therefore all maintenance and repairs are done onboard. With the Orlan spacesuits it was possible to build the complex

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first permanent space station Mir and to service and maintain the station operational for 17 years, although the design life was only five years.

The tragic accident of Soyuz 11, with the loss of the crew, forced back the use of rescue suits for all ascent and descent phases of the Soyuz flights. Zvezda developed a successful rescue-suit family, the Sokol, to be used on all Soyuz flights from Soyuz 12 on. For the crews of the Buran space plane, a special rescue suit, Strizh, was developed for emergency situations using ejection seats.

Introduction

The first decade of Soviet spacesuit development, the 1960s, was characterized by the space race. In a brief period of time a number of spacesuits, experimental and operational ones, were developed and tested. But only some were used in actual spaceflight. However, these missions were all "world's first," not only for spacesuit operations and EVAs but also, for example, the first human spaceflight by Yuri A. Gagarin in Vostok 1, the first EVA by Alexey A. Leonov in Voshkod 2, and the first in-orbit crew transfer by Aleksei S. Yeliseyev and Yevgeny V. Khrunov from Soyuz 5 to Soyuz 4. At the end of this first decade, the operational status of the Krechet and Orlan suits for the Soviet lunar program had also been reached (Figure 1).[1]

The Origin: Spacesuits for Almaz Versus Salyut Orbiting Stations

As far back as the second half of the 1960s, in parallel with the Soviet lunar program at TsKBEM (earlier OKB-1, later RSC Energia), the TsKBM (earlier OKB-52, later NPO Machinostroyenia) led by Vladimir N. Chelomey was involved in the development of the Almaz orbiting station. The Almaz program required the use of an EVA spacesuit, primarily to support transfer of crew members from a transportation vehicle to the orbital module. At the time of the start of the Almaz program, the Yastreb was the most developed system. Therefore this suit was initially selected for the use in the Almaz program in 1967.

At the same time, the problem of using rescue suits in the most dangerous phases of the mission was still pending. In particular, such a requirement was valid for the Soyuz 7K-VI space vehicle (military application model) and the Almaz system transportation vehicle, TKS. Thus, when selecting a suit concept for the orbiting station, it seemed impossible to get around the problem of using a universal spacesuit. However, requirements of the EVA and rescue suits were rather different. Therefore, proceeding from the fact that EVA performed from an

orbiting station would become routine, Zvezda specialists proposed the use of two different types of spacesuits for these space missions, namely a light-weight individually tailored rescue suit and a more efficient EVA spacesuit of a semi-rigid type, on the basis of the Orlan spacesuit for the lunar mission commander.

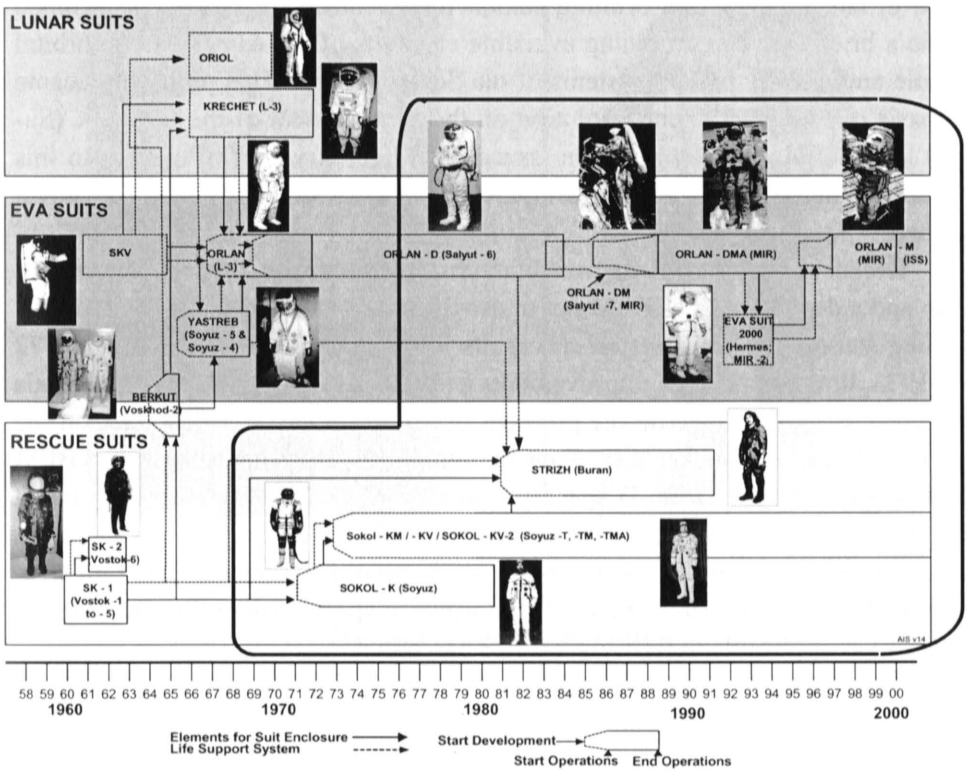


Figure 1: Soviet/Russian spacesuits.[2] Credit: Archive Skoog.

After thorough feasibility studies and fit checks of the Orlan spacesuit in the Almaz mock-up, on 20 November 1969, TsKBM jointly with Zvezda made a decision to use the Orlan spacesuit in the Almaz program.

> In accordance with results of feasibility studies carried out in line with the Government Directive dated July 3, 1968, this Directive nullifies the earlier approved documents on the application of the Yastreb type spacesuit on the Almaz orbiting station and approves application of a new and more advanced spacesuit of the Orlan type.
>
> The Orlan spacesuit is designed to support extravehicular activity of one or two crew members . . . and manoeuvring with the use of an individual propulsion system (to be ordered by the TsKBM in accordance with a separate Performance Specifications).

The same decision required the spacesuit to support a five-hour EVA period for the Almaz station and from two to four EVAs to be performed within two-and-one-half months.

Because of delays in planned activities on the Almaz program and the coming launch of the U.S. Skylab station, a group of TsKBEM specialists proposed in late 1969 that an orbiting station for scientific purposes be developed within a brief time by combining available elements of the Almaz station orbital module and already proven systems of the Soyuz vehicle. This proposal became the basis of the government resolution on the development of the DOS-7K (Salyut) long-duration orbiting station issued on 9 February 1970. Pursuant to this resolution, the Orlan spacesuit development was initiated as applied to the Salyut station.

Because of delays in the manufacturing of hardware for the Almaz program and a decision of TsKBEM not to use the Orlan-D spacesuit on the Salyut 1 orbiting station, the activities on spacesuits for an orbiting station were, in 1972 and 1973, limited to design improvements and various tests. In May 1973 Zvezda requested TsKBEM to settle the problem of using the Orlan-D spacesuit on the Salyut stations in a quicker way. Soon an agreement was reached with TsKBEM to start operating the Orlan-D spacesuit on the Salyut 6 station. The agreement was documented in January 1974 by the joint TsKBEM/Zvezda Decision No. 2/511-74 and followed by the Inter-Agency Committee decision dated 18 September 1974. In June 1974 the final performance specifications for the Orlan-D spacesuit as applicable to the Salyut 6 was agreed on.

Then Orlan-D flight units 33 and 34 and back-up systems 35, 36, and 38 were prepared for installation onboard the Salyut 6 station (Figure 2). At the same time, cosmonauts were trained in thermal vacuum chambers (at Zvezda and the Air Force Scientific Research Institute), neutral bouncy facilities, and aboard the Tu-104 flight test bed.

In those years, the activities on the Orlan-D spacesuit for the Almaz program did not stop. In particular, the Orlan-D spacesuit was tested in the TBK-60 thermal vacuum chamber and participated in the interagency tests of the Almaz station life support system. On the completion of the Salyut 6 mission and the final termination of the Almaz program, further activities with the Orlan-D spacesuit for this program were stopped.

As is known, the first EVA supported by the Orlan-D semi-rigid spacesuit was performed from the Salyut 6 orbiting station on 20 December 1977, by cosmonauts Yuri V. Romanenko and Georgi M. Grechko. Since then, such spacesuits, continuously improved and produced in several modifications, have become the standard in-orbit based EVA spacesuits. They have been placed on-

board the Salyut, and later Mir and ISS, orbiting stations enabling practically all crew members of these stations to work in free space.

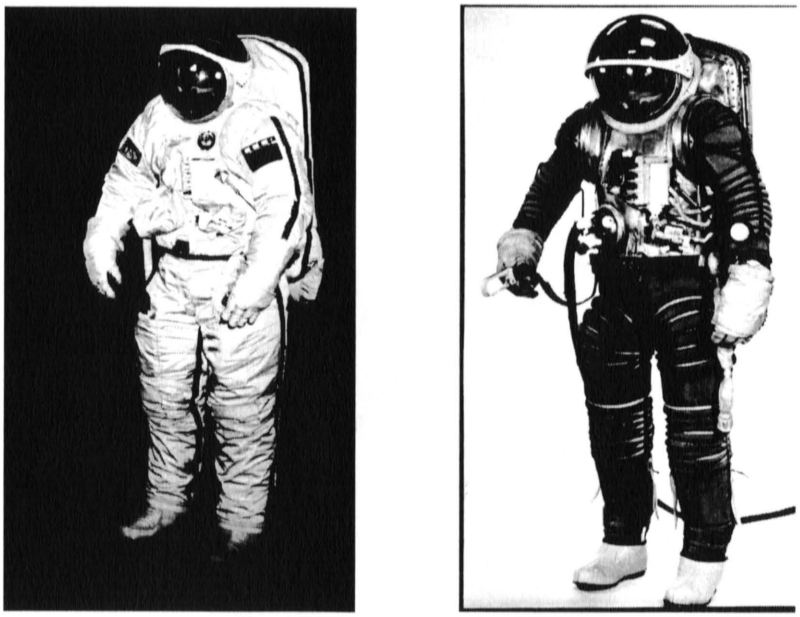


Figure 2: Orlan-D EVA spacesuit, with and without garment. Credit: Archive Zvezda.

Orlan General Concept

The Orlan-type, spacesuit design concept was selected proceeding from the following considerations. No single failure of the spacesuit elements shall result in the failure to fulfill the EVA program. The failures resulting in catastrophic consequences shall be excluded completely. The basis of this concept was to make the vitally important functions redundant either at the element level or at the subsystem level. Those spacesuit elements, the damage of which may result in the loss of pressure tightness, were made redundant. Thus, the spacesuit uses a dual visor system and dual pressure bladder enclosures of soft pressure parts. Moreover, the back-up pressure bladder becomes operational automatically in case the main bladder fails. Disconnects and movable joints of the spacesuit (suit entrance interface and pressure bearings) feature dual barrier sealing.

The selection of a semi-rigid design concept of the spacesuit with application of joints and pressure bearings on soft parts of the suit made it possible to use a rather high operating pressure of the 400 hectopascal and thus to minimize prebreathing time for crew members prior to the EVA period practically without any risk of decompression sickness.

Application of the water-cooling garment in combination with effective operation of the sublimation heat exchanger provides a stable thermal balance of the crew member for workloads up to 600 watts.

Development and demonstration tests were mainly carried out at Zvezda test facilities, including the most important human-rated tests in a vacuum chamber. To support the test program, Zvezda developed the TBK-50 vacuum chamber, which enabled Zvezda to run human-rated tests and train cosmonauts with two Orlan-type spacesuits simultaneously involved in the test/training session (Figure 3).

Figure 3: Orlan-type suit testing in the TBK-50 thermal and vacuum chamber at Zvezda. Credit: Archive Zvezda.

There have been four main modifications of the Orlan-type suit taking place. Changes in the design of the spacesuit and its systems resulted from new operations conditions, new tasks set for crew members involved in EVA and experience gained in suit operations, recommendations of cosmonauts, new design ideas, and improvement of reliability and operation life.

The Orlan-D spacesuit (Figure 2), the first modification/member of the Orlan family, was used in the Salyut 6 and Salyut 7 missions. The next modification, the Orlan-DM spacesuit, was an intermediate stage for Salyut 7 and Mir before the Orlan-DMA came to life. EVA suits used in the Mir program were the Orlan-DM (the first two years), Orlan-DMA, and Orlan-M. Used within the ISS program were the Orlan-M spacesuits.

Orlan-D

The Orlan-D spacesuit modification (a derivative of the spacesuit for a commander of the lunar mission) was mainly developed in the period from 1969 through 1974 proceeding from the requirements and specific features of operations aboard the orbiting station, namely multiple use with a durable stay of the suit onboard the station *without* return to Earth, change of crews with different anthropometric characteristics, necessity to check and prepare suits for repeated EVA onboard the station by crew members, and increased duration of EVAs.

The units in the spacesuit backpack were completely rearranged and the suit life support system (LSS) flow diagram was considerably changed (Figure 4). To begin with, the oxygen bottles and contaminant control cartridge were made easy access and refilling the LSS cooling system with water was provided. An evaporating heat exchanger was replaced with a sublimator. The main bottle was transferred from the backpack internal cavity to its external surface (in the lower part of the backpack) to facilitate its replacement.

In the period from 1977 through 1984, crew members wearing the Orlan-D spacesuits performed three EVA sessions from the Salyut 6 orbiting station and ten EVAs from the Salyut 7 station.

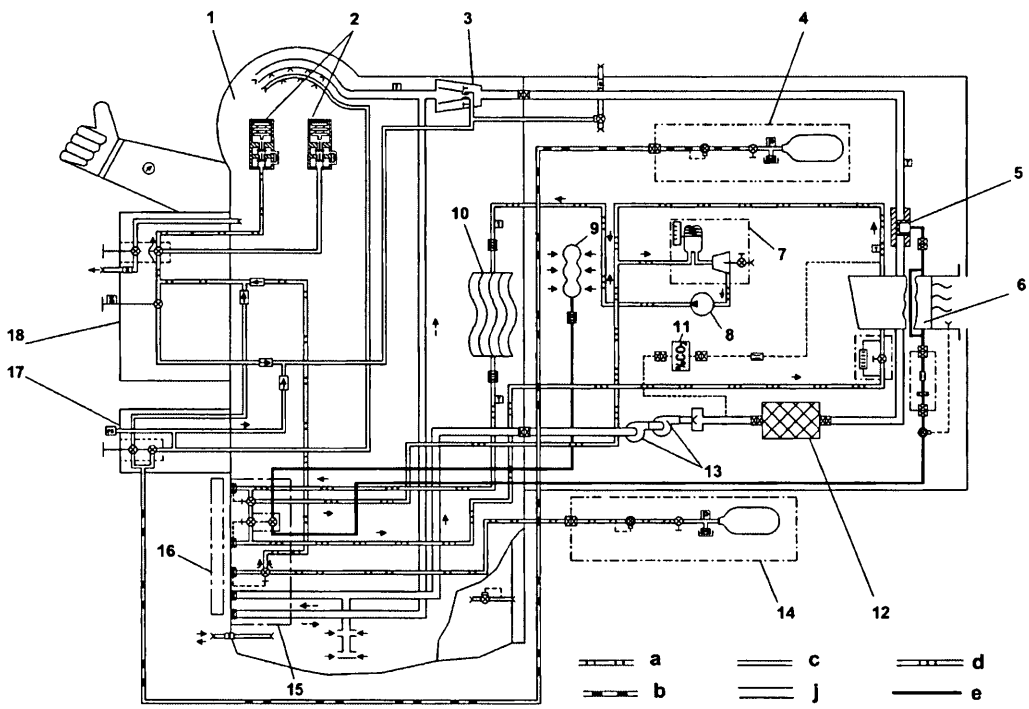


Figure 4: Principal flow diagram of the Orlan-D self-contained LSS (Salyut 7 version). Credit: Archive Zvezda.

Utilization of the Orlan-D spacesuit was also intended for the Buran reusable space transportation system (it was agreed on with the TsKBEM in a protocol dated 16 October 1980). The plan was to perform three, five-hour EVA sessions during a seven-day Buran system mission and from six to eight EVA sessions for a thirty-day mission. Air locking could be carried out either in the Buran airlock (ShKK) or in the vehicle docking module.

Orlan-DM

The Orlan-D spacesuit was connected to the station onboard systems by a 20-meter umbilical, which was used to supply the spacesuit with electric power, to support radio communications, and to transmit telemetry data about operation of the suits and state of the crew member. The cable communications of the spacesuit with station onboard systems was only acceptable when crew members performed activities on the station surface nearby the airlock. Therefore, after successful operation of the EVA spacesuit in the Salyut 6 mission, the start was given for the Orlan-DM modification, a new member of the Orlan family, which could be transformed, in future, to a completely self-contained spacesuit (mainly by adding a removable unit with additional equipment). In 1983, the specifications were approved and 16 Orlan-DM spacesuits were ordered.

A new panel, designed to control electric and radio communications systems, was developed for the Orlan-DM spacesuit. Mobility of the suit arms and legs was improved and a combined control panel for the pneumatic and hydraulic systems developed. An emergency oxygen hose was introduced, the cooling areas of the water cooling garment were decreased, and lamps were installed on the suit helmet.

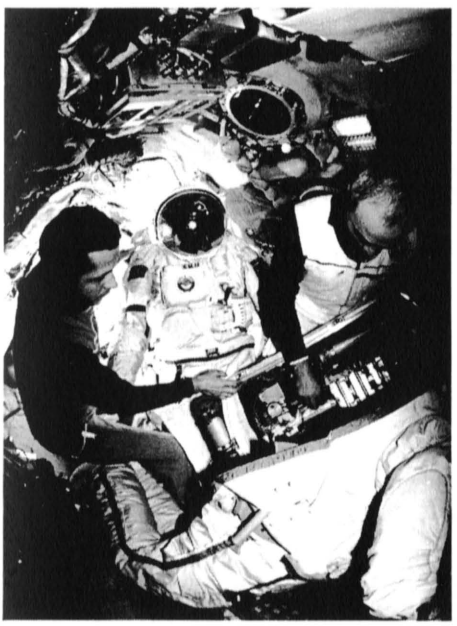
The first Orlan-DM spacesuits were delivered to the Salyut 7 station in the middle of 1985 (Figure 5), and the same type of suits was delivered to the Mir station in March 1986. Within the Mir program, the Orlan-DM spacesuits supported five EVA sessions each (the last one on 30 June 1988). Then they were replaced with the Orlan-DMA spacesuits.

Orlan-DMA

The Orlan-DMA spacesuit (Figure 6) was modified to be used without an electric umbilical connecting the suit with onboard station systems. It was equipped with a special removable unit at the bottom of the backpack, containing the power supply, radio communications, and telemetry system units. Suit pressure gloves were improved and the utilization of pressure cuffs, which retained the suit pressure for some time in case of damage to gloves, was provided. Other improvements and changes included an increase in duration of the suit and the

autonomous operation mode up to six hours. The Orlan-DMA was to become the main suit for the Mir station, where 10 suits were used in 112 human sorties (56 EVAs).

The development of a completely self-contained spacesuit system was carried out within the "Suit-UPMK (Cosmonaut Transference and Manoeuvring Unit) System." Therefore the Orlan-DMA suit was fitted with a system to permit cosmonaut maneuvering without an umbilical (identified as the 21KS system), which was flight tested successfully in 1990 (see below).



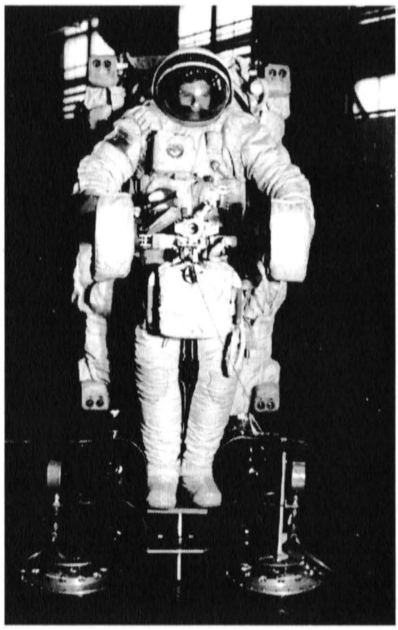


Figure 5 (left): Cosmonauts Vladimir A. Dzhanibekov and Viktor P. Savinykh preparing the Orlan-DM suits for an EVA from Salyut 7 orbital station (OS). Credit: Archive Zvezda.

Figure 6 (right): A test subject suited in the Orlan-DMA with the 21KS is on the test facility with aerostatic supports. Credit: Archive Zvezda.

After development of the Orlan-DMA spacesuit, in 1987 the decision was made to also use it in the Buran program, instead of the Orlan-D spacesuit. At the same time, a start was given to activities on the further modification of the spacesuit as applied to the planned Mir 2 orbiting station.

EVA Suit 2000

In 1990–1992 Zvezda had provided system support to Dornier in Germany for the development of the European Space Agency (ESA) Hermes spacesuit,

European Space Suit System (ESSS). On the initiative of Dornier and Zvezda, ESA and the Russian Space Agency started, in 1992, a feasibility study and then the development of a design concept of a joint Russian/European EVA suit of a new generation, which was to be used both for the Hermes and the Buran-type vehicles and for the then planned Russian Mir 2 station. Utilization of the already available Zvezda test facilities and experience would enable ESA to decrease the cost for the development of the spacesuit. Russian specialists found many similarities in the European Hermes spacesuit concept ESSS design and the concepts used in the Orlan-type spacesuits. As a result, development of the EVA SUIT 2000 was based in many respects on those same concepts.

When the joint U.S./Russian Statement on Space Cooperation (Gore-Chernomyrdin Commission) about participation of Russia in the ISS program was signed in 1993, and when its activities on the Hermes, Buran, and Mir 2 programs were terminated, the EVA SUIT 2000 was planned to be used in the Russian segment of the ISS. However, late in 1994, when activities on ISS were intensified, ESA initiated termination of the EVA SUIT 2000 project because of financial constraints. Thus, Zvezda renewed activities on the earlier started modification of the Orlan-type suit but now applicable to the ISS program. Certain ideas worked out by Zvezda in the EVA SUIT 2000 project were seen materialized in the new spacesuit modification, Orlan-M.

Orlan-M

With new requirements and operations experience from the Mir station taken into account, changes introduced into the Orlan-M spacesuit design for operations on ISS were the increased spacesuit body dimensions and enclosure height adjustment envelope, additional visor to improve the upper field of view (Figures 7 and 8), protective visor to prevent helmet visor fogging, elbow and ankle pressure bearings, pressure glove of improved mobility and strength, wrist pressure disconnect of improved reliability, water cooling garment of improved performance characteristics, safety tether of variable length widening the cosmonaut operating envelope, back-up pump, modified fan, modified radio set, CO_2 absorption cartridge of increased capacity, and others.

Changes introduced in the hard torso with transfer of the exit hatch up, increase in the rear part of the helmet, and increase in length of leg enclosures made it possible to significantly facilitate suit donning/doffing and accommodation, and also increased acceptable crew member anthropometric dimensions, 112 centimeters for the chest (instead of 108 centimeters in the Orlan-DMA case) and 190 centimeters for the height (instead of 185 centimeters) to meet U.S. standards.

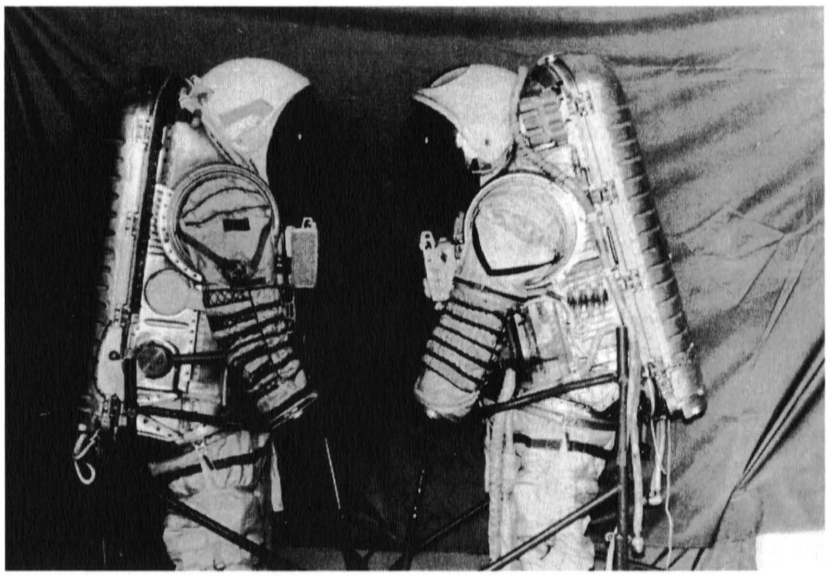


Figure 7: External configuration and backpack differences between Orlan-DMA (left) and Orlan-M (right). Credit: Archive Zvezda.

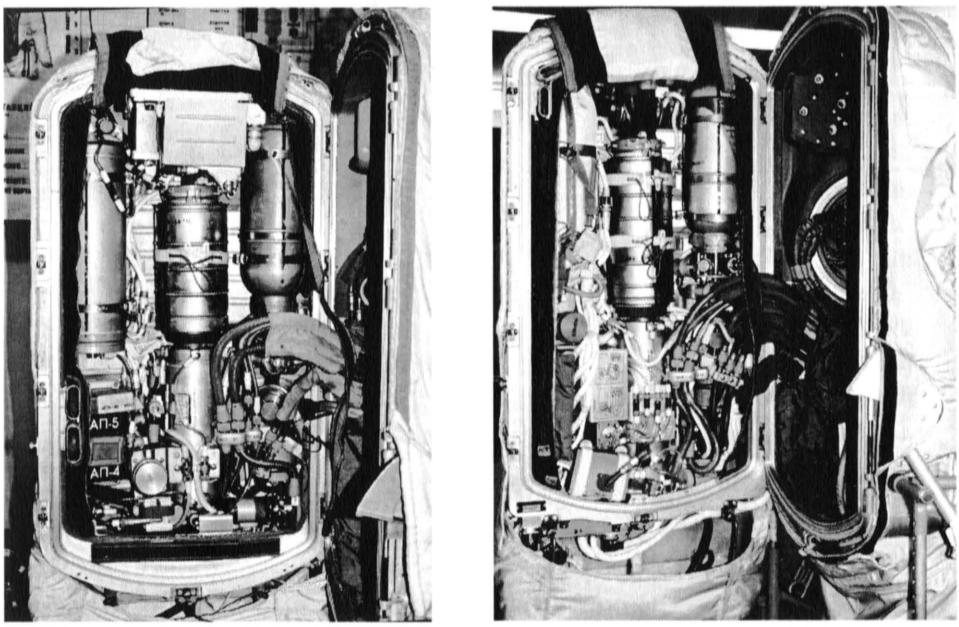


Figure 8: Backpack differences Orlan-DMA (left) and Orlan-M (right). Credit: Archive Zvezda.

When all required tests were completed, Orlan-M spacesuits 4, 5, and 6 were delivered to the Mir OS in 1997. They accumulated 36 human EVAs. The

date of the last EVA sortie was 12 May 2000 (Figure 9). Two Orlan-M spacesuits (#12 and #23) were delivered to ISS in the service module in July 2000, and one Orlan-M suit (#14) was delivered to ISS in the Stikovochniy Otsek 1 (SO-1) docking module in September 2001. By 31 December 2002, 11 Russian and U.S. crew members had performed 18 human-EVAs using the Orlan-M spacesuits onboard ISS.

A considerable amount of work was done for integration of the Orlan spacesuit with the ISS common airlock. Zvezda specialists managed to make a new small size onboard system for the spacesuit, which provided interoperability of the Orlan spacesuit both with the Russian segment airlocks and also station common airlocks. The spacesuit was modified correspondingly. Unfortunately the decision on the possibility to use the Orlan-M in the common airlock has not yet been made (as of 2003).

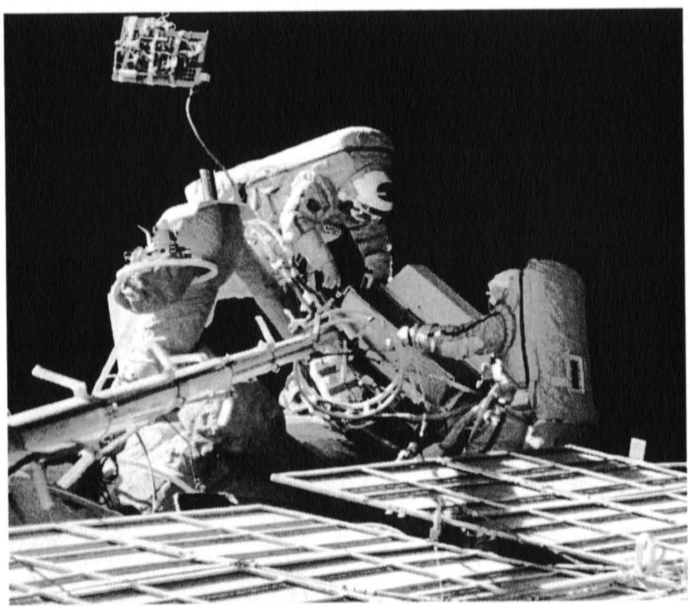


Figure 9: Orlan-M suit during EVA in the Mir OS. Credit: Archive Zvezda.

Orlan Training Suits

Besides the above described four modifications of the orbit-based spacesuit, Zvezda developed several special test and training models: Orlan-V, Orlan-GN, and Orlan-T. These models made it possible to run training in the hydraulic laboratory of the Cosmonaut Training Centre (Orlan-GN), in weightlessness conditions onboard the flying laboratory (Orlan-V), and in ground training in a special airlocking simulator (Orlan-T).

Orlan Operational Results

The list of EVA sorties performed from the Salyut 6, Salyut 7, Mir, and ISS orbiting stations and supported by the Orlan-type spacesuits is given in Table 1. There was no single case of decompression sickness of crew members involved in EVAs. The gained experience proved that a spacesuit of a semi-rigid type was the most suitable for EVAs performed to support operations of a long-duration orbiting station. Suit operations results also demonstrated advantages of the selected approach to use spacesuits specially designed to support EVA. It is appropriate to indicate that in-orbit operations of spacesuits onboard orbiting stations for several years without return to Earth, and their utilization by many crews, have been accomplished for the first time in space history.

Orbiting Station	Spacesuit		EVAs	Delivery to Orbit	Date of Last Use	Operations Period
Salyut 6	Orlan-D	#33	3	Sep 1977	15 Aug 1979	1 yr 9 mth
Salyut 6		#34	3	Sep 1977	15 Aug 1979	1 yr 9 mth
Salyut 7		#45	10	Apr 1982	8 Aug 1984	2 yrs 4 mth
Salyut 7		#46	3	Apr 1982	3 Nov 1983	1 yr 7 mth
Salyut 7		#47	7	Mar 1984	8 Aug 1984	0 yr 5 mth
Salyut 7	Orlan-DM	#8	3	Jun 1985	31 May 1986	≈ 1 year
Salyut 7		#10	3	Jun 1985	31 May 1986	≈ 1 year
Mir		#7	5	Mar 1986	30 Jun 1988	2 yrs 3 mth
Mir		#9	5	Mar 1986	30 Jun 1988	2 yrs 3 mth
Mir	Orlan-DMA	#6	14	Jun 1988	27 Jul 1991	3 yrs 1 mth
Mir		#8	10	Oct 1989	20 Feb 1991	1 yr 4 mth
Mir		#10	9	Aug 1988	21 Apr 1991	2 yrs 8 mth
Mir		#12	7	Oct 1989	20 Feb 1991	1 yr 4 mth
Mir		#14	13	Apr 1991	22 Oct 1993	2 yrs 6 mth
Mir		#15	7	Apr 1991	18 Jun 1993	2 yrs 2 mth
Mir		#18	13	Oct 1992	8 Dec 1995	3 yrs 2 mth
Mir		#25	15	Mar 1993	13 Jun 1996	3 yrs 3 mth
Mir		#26	12	Oct 1995	20 Oct 1997	2 years
Mir		#27	12	Feb 1995	20 Oct 1997	2 yrs 8 mth
Mir	Orlan-M	#4	14	Apr 1997	12 May 2000	3 yrs 1 mth
Mir		#5	12	Apr 1997	16 Apr 1999	2 years
Mir		#6	10	Oct 1997	12 May 2000	2 yrs 7 mth
ISS	Orlan-M	#12	7	Jul 2000	25 Jan 2002*	
ISS		#14	4	Sep 2001	26 Aug 2002*	
ISS		#23	7	Jul 2000	26 Aug 2002*	

* Status by 31 December 2002.

Table 1: Orlan type spacesuit operations.[3]

The most substantial maintenance and repair activities performed on the Orlan-type spacesuits onboard the orbiting stations were as follows: repair of the suit leg enclosure (1983); replacement of the fan unit (1991 and 1998); replacement of the suit arm resulted from introduction of the pressure cuff (1990) and increased leakage (1998 and 2000); replacement of the Beta-08 medical data processing unit (1998); and replacement of the leaking water valve on the suit combined service connector (1999).

The most unique repair occurred in 1983 on the Salyut 7 station when cosmonauts managed to repair the damage of the main suit pressure bladder. In 1982, the first-shift crew members of the Salyut 7 OS successfully performed four EVA sessions using two Orlan-D spacesuits. The next EVA session was scheduled to be performed on 1 November 1983 by Vladimir Lyakhov and Aleksandr Aleksandrov, members of the next space crew, with the use of the same EVA suits after the suits had been stored in space for more than a year. However, the crew members performing pre-EVA checking of the suits on 26 October revealed leakage in one of the spacesuits. The suit leaked under the knee of the right leg. In line with the recommendation of the ground support team, the cosmonauts removed the stitches of the longitudinal seam of the restraint enclosure, opened it to find a rupture of the main pressure bladder, as long as two-thirds of the bladder transverse perimeter. The subsequent analysis showed that the most probable cause of such a rupture was improper stowage (too compact) of the suit for long-term storage by the previous crew. Testing of the suit for leakage showed that the back-up pressure bladder was intact.

A repair procedure using in-orbit only equipment (sheet metal, sewing equipment, soldering iron, and cloth) was developed and tested on the ground. On 29 October the repair procedure and sketches were transmitted to the crew by radio, and the next day, 30 October, the crew repaired the spacesuit and carried out all needed tests (Figure 10). On 1 and 3 November 1983, the scheduled EVA sessions were successfully performed.

The Maneuvering Units, UPMK

Early activities on UPMK for the soft SKV suit were completed with a design review in 1965. Initially this program was run in accordance with the government directive dated 27 July 1965 concerning the two additionally ordered Voshkod spacecraft (with the use of the Volga soft airlock). It was planned to use the Yastreb spacesuit on those spacecraft. On termination of the Voshkod spacecraft program, UPMK development was continued by the government directive dated 28 December 1966 for the Almaz program, where it was also planned to

use the Yastreb spacesuit (Figure 11). When the Yastreb spacesuit was changed to the Orlan spacesuit for EVAs from the Almaz station, the decision of Zvezda and TsKBM, in 1969, was to develop UPMK for the Orlan spacesuit. But further activities on UPMK were stopped, because at that time there were no specific tasks to be performed using UPMK.

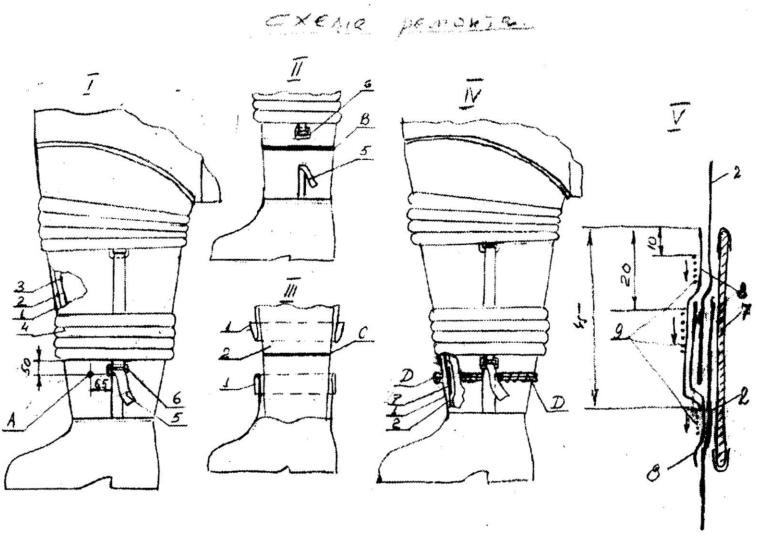


Figure 10: Illustrations for the Orlan-D suit leg repair, which were transferred to the Salyut 7 OS. Credit: Archive Zvezda.

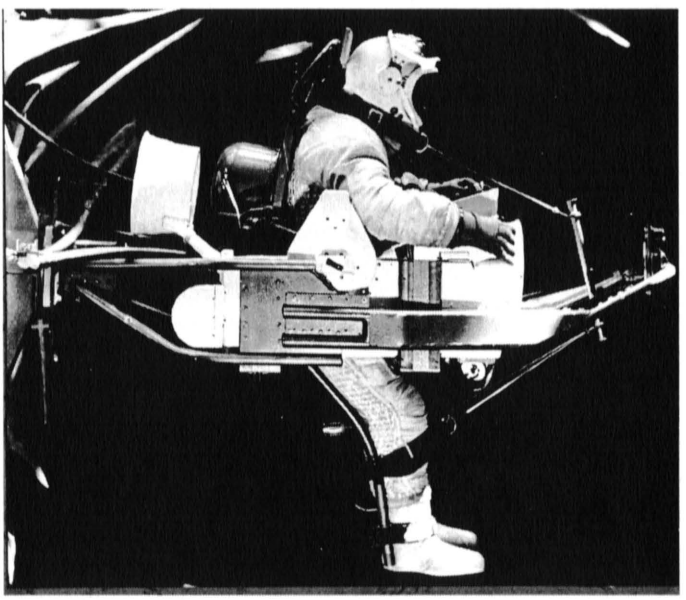


Figure 11: UPMK on Yastreb spacesuit. Credit: Archive Zvezda.

Later in 1984 these activities were resumed as applied to missions to the Mir OS, where the Orlan-type spacesuits were also used for EVAs. The 21KS unit was a self-contained system, including the propulsion. The unit was designed to be used by cosmonauts during EVA for transfer in the open void. A cosmonaut operating the unit is able to perform activities and move about the spacecraft with no use of a safety tether, handrails, or feet anchor elements located on the spacecraft surface. The UPMK application in the orbiting station should make it possible to increase efficiency of cosmonaut activity in space during activities on assembly, repair and preventive maintenance, research, military application, and wrecking (Figure 6).

In 1990 Aleksandr A. Serebrov flew the 21KS during 40 minutes and moved away from the station for 33 meters. Aleksandr S. Victorenko flew the 21KS during 93 minutes and moved away from the station for 45 meters. All the 21KS systems functioned properly.

Unfortunately further operations of the Mir OS did not set the task of using the 21KS, but Zvezda used the unique experience gained during its development for development of the Simplified Aid for EVA Rescue (SAFER). SAFER was designed to provide for return of the cosmonaut wearing the Orlan-M spacesuit to the ISS surface, in case of accidental separation from the station during EVA, and is similar to the U.S. extravehicular mobility unit (EMU) SAFER. In 2001–2002 Zvezda completed SAFER development by contract with Rosaviakosmos and manufactured the flight samples for delivery to ISS. But in 2003 the decision on their usage had not yet been made.

Sokol, Soyuz Rescue Suits

In the second half of 1969 in connection with the development activities of the Salyut orbiting station, the Soyuz transport spacecraft was modified. The modified Soyuz enabled the space crew to transfer from it to the OS through an inner passage in the docking system without a sortie into open space. Thus there was no need for the Yastreb spacesuit and the self-contained life support system (SCLSS) any more in this spacecraft (now index 7K-T instead of 7K-OK).

The first flight of this new series spacecraft (Soyuz 10) to the Salyut OS (Salyut 1) with a three-member crew was on 23–25 April 1971. Zvezda supplied the flight garments, shock-absorbing seats, waste management system, drinking water system, and survival kits for these new spacecraft. The use of rescue suits in the Soyuz spacecraft type 7K-T was, as in the previous 7K-OK spacecraft, according to TsKBEM (OKB-1) documentation still not foreseen.

The second flight with Soyuz 11 to the Salyut OS (Salyut 1) had a tragic ending. On 30 June 1971 cosmonauts Georgy T. Dobrovolsky, Vladislav N. Volkov, and Viktor I. Patsayev perished due to a sudden spacecraft depressurization in the descent phase of the mission. After that, based on conclusions made in August 1971 by a specially organized governmental commission on accident investigation chaired by Mstislav V. Keldysh, a number of actions were taken to improve crew safety. Zvezda was given the task to design protective gear compatible with the personal couch liners of the Soyuz spacecraft shock-absorbing seats in the briefest possible time and with a minimum of modifications of the descent vehicle (DV).

Sokol-K

None of the earlier developed spacesuits (SK-1, Berkut, or Yastreb) could be used for this purpose, as they were basically designed for cosmonaut protection outside of the spacecraft or were not compatible with the shock-absorbing seat.

Several versions of the protective equipment were considered: for example, the light-weight full pressure suit designed on the basis of the Sokol aviation pressure suit. Fit checks of such flight gear mock-ups with the Kazbek seat couch liners (Figure 12) and analyses for feasible oxygen supply systems and the associated mass were performed. As a result of this activity, the optimum version was selected: a lightweight, full-pressure suit with a soft fixed helmet, with a sliding visor, and an open-type LSS designed for two hours of operation.

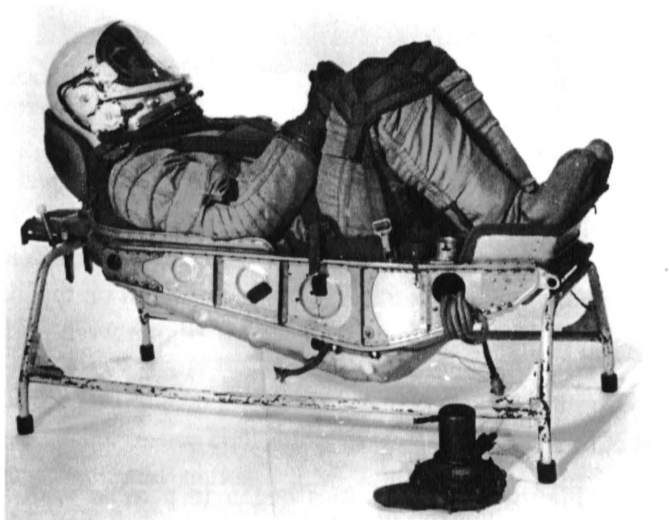


Figure 12: Sokol aviation suit in the Kazbek shock-absorbing seat.
Credit: Archive Zvezda.

But the Sokol aviation pressure suit adopted as a prototype for the rescue suit required considerable modifications. The suit was configured in such a way that it supported a cosmonaut to take an "embryo" posture in the shock-absorbing seat dictated by the DV cabin dimensions and requirements on withstanding acceleration (Figure 13). The new rescue suit for the Soyuz spacecraft was called Sokol-K ("K" for "space"). The mass of the new suit was 9–10 kilograms. The suit donning time was 10–12 minutes. A person wearing this suit could survive up to several hours in cold water. A special floatation collar was available (in the survival kit) to provide stable and comfortable posture afloat.

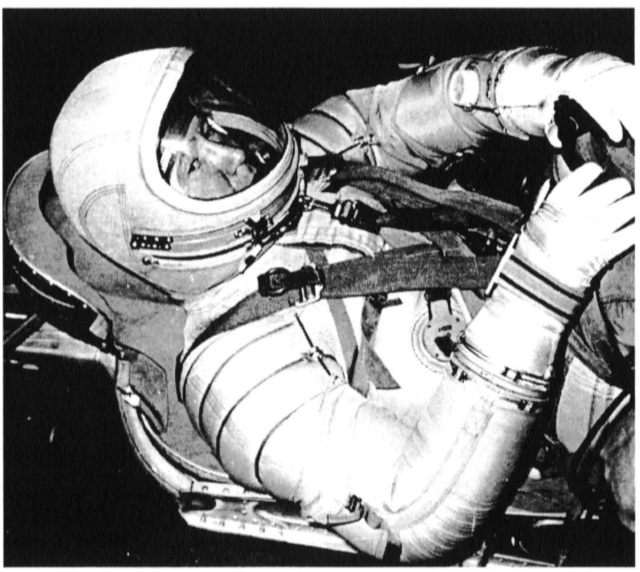


Figure 13: Cosmonaut Alexey A. Leonov suited in Sokol-K in the Kazbek seats. The suit was pressurized to 400 hectopascal. Credit: Archive Zvezda.

The full complex of in-house engineering and physiological tests of the rescue suit was completed by mid 1972. The day of 27 September 1973 was the day when the flight operation of the Sokol-K rescue suit started. Vasili Lazarev and Oleg Makarov, who took off in the Soyuz 12 spacecraft on that day, were the first to use them. All subsequent Soyuz spacecraft flights were performed with those suits.

Sokol-KV and KV-2

The Sokol-K improvement activities began in parallel with the Sokol-K rescue suit operations in late 1973. Several versions of spacesuit modifications were developed in series, for example, the spacesuit pressurization was simpli-

fied, the pressure regulator location was changed, and a version with water-cooling (Sokol-KV) was developed. The decision was finally made to continue the development of the Sokol-KV suit without the water-cooling system for the Soyuz spacecraft because this system would complicate the operation of the suit and the spacecraft, and there was no absolute necessity for it. Finally the V-shaped zipper concept was introduced for the operational version, Sokol-KV-2 (Figure 14). Cosmonauts Yuri V. Malyshev and Vladimir V. Aksyonov performed the first mission using the Sokol-KV-2 suits in the Soyuz T-2 spacecraft on 5 June 1980. In 2003, the Sokol-KV-2 suits were still being successfully operated in the Soyuz TM and TMA spacecraft, including by the ISS crews.

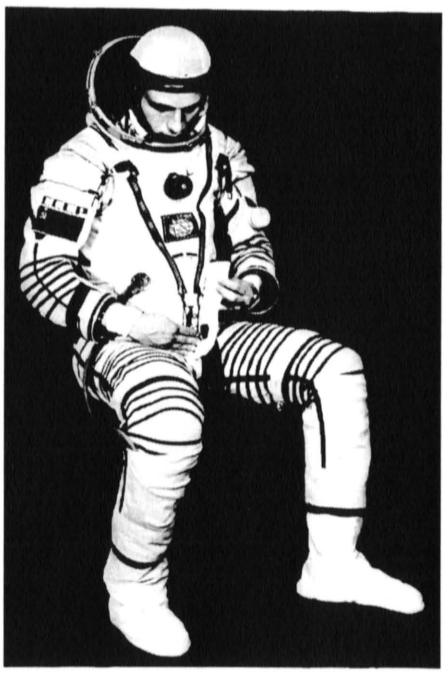


Figure 14: Sokol-KV-2 rescue suit. Credit: Archive Zvezda.

Strizh: Buran Rescue Suit

Zvezda received the preliminary specification from NPO Molniya, on 22 July 1976, for the preliminary design of a number of subsystems and components for the Buran space plane, consisting of the personal LSS, including a full-pressure rescue suit and onboard LSS, and an EVA spacesuit with a self-contained LSS. One of the challenges was to develop a closed regenerative system with long-duration operation for the rescue spacesuit.

Development of the full-pressure rescue suit, part of the Buran space plane portable life support system (PLSS), was initiated in 1977 by manufacture of test samples on the basis of the Sokol-KV and Sokol-KV-2 full-pressure suits. In 1981 the selected experimental sample was named Strizh (translated "swift") (Figure 15).

The main task at the first stage of development of the suit enclosure was concentrated on the built-in restraint harness, which would play the role of the seat-restraint system and the parachute suspension harness, besides a function of the suit-restraint system. The second task was to provide the required suit/ejec--tion seat compatibility, that is, crew-member capability to perform necessary work operations on spacecraft piloting, including forward inclinations and taking the ejection posture under positive pressure in the suit. Strizh also had provisions for drinking with the helmet closed. The final performance specification required a 12-hour, closed-loop operation of the suit at 440 hectopascal in the depressurized cockpit "operations" mode.

Figure 15 (left): Front opening of Strizh. Credit: Archive Zvezda.

Figure 16 (right): Appearance of the Strizh suit helmet bubble after the aerodynamic heat test. Credit: Archive Zvezda.

One of the main requirements for the Strizh suit was the crew-member rescue by ejection in the initial active portion of the mission (ascent) at altitudes up

to 30 kilometers and Mach number up to 4. Moreover, there was heavy heating of the suit, besides high aerodynamic loads. In connection with this, a special thermal resistant fabric for the suit restraint layer was developed and used. To provide additional thermal protection, the external thermal protection layer of the suit enclosure was developed. It was made of elastic leather with aluminum coating. The helmet visor was made double in order to improve reliability, provide additional thermal protection, and prevent fogging (Figure 16).

The maiden flight of the Buran space plane took place on 15 November 1988 in a robotic configuration. The flight units of all main items developed by Zvezda were installed in the space plane, including two ejection seats, rescue suits with mannequins, and the onboard LSS designed for the rescue suits. It was planned to perform the second seven-day, uncrewed flight with a docking to Mir space station. In connection with known political events of 1991, the Energia-Buran reusable space system was transferred from the military program to the government civil space program. In 1992 Rosaviakosmos decided to stop the activities on this program because of reduction of finances for the space program.

Conclusions

By 31 December 2002, Orlan-type spacesuits had accumulated 208 human EVAs, with a total duration exceeding 850 hours, performed from the Salyut, Mir and ISS OS. Members of 45 crews, including French and ESA cosmonauts and NASA astronauts, participated in these EVAs. The total number of the Orlan-type spacesuits (four modifications) used onboard the stations during the given period is 25, and some of them were in-orbit for up to two to three years.

The Orlan spacesuit design has shown a remarkable reliability and a unique capability for in-orbit maintenance and repair. The in-orbit based concept has been proven viable, a capability needed for future systems in order to provide economical and operational flexibility.

References

[1] Å. I. Skoog and I. P. Abramov, "The Soviet/Russian Space Suits—A Historical Overview of the 1960s," *Acta Astronautica* 51 (July–November 2002): pp. 133–143. I. P. Abramov and Å. I. Skoog, *Russian Space Suits* (Chicester, United Kingdom: Springer Verlag, Heidelberg, and Praxis Publishing, 2003).

[2] Abramov and Skoog, *Russian Space Suits,* 2003.

[3] Abramov and Skoog, *Russian Space Suits,* 2003.

Appendix: The Main Characteristics of the Orlan-Type Spacesuits

Characteristic	*Spacesuit model/modification*						
	Orlan	**Orlan-D** *Salyut 6*	**Orlan-D** *Salyut 7*	**Orlan-DM** *Mir*	**Orlan-DMA** *Mir*	**Orlan-M**	
						Mir	*ISS*
Beginning of suit operation (year)	(1969)	1977	1982	1985	1988	1997	2001
Guaranteed number of EVAs	(2)[1]	6	10	10	10	12	12+15
Total work duration (in one cycle), max hours	5	5	7	8	9	9	9
Duration of CO_2 removal cartridge operation, hours	5	5	5	6	7	7	9
Duration of autonomous operation (in one cycle), hours	5	5	5	6	6+1	6+1	6+1
Life time, years	2.5	3.5	4	4	4	4	4
Wet mass, kg, max.	59	73.5	73.5	88	105	112	112
Stored O_2, kg							
—primary	0.5	1	1	1	1	1	1
—reserve	0.2	1	1	1	1	1	1
Feedwater capacity, kg	2.5	2.9	2.9	2.9	3.6	3.6	3.6
Heat removal, watts							
—average	250	300	300	300	300	300	300
—maximal	600	600	600	600	600	600	600
Electric power supply	umbilical	umbilical	umbilical	umbilical	battery since 1990 (umbilical)	battery (umbilical)	
Consumed power, watts	30	32	32	32	42	54	54
Number of measured parameters	3	14	14	17	23	26	29[2]
SS pressure, hPa							
—primary mode	400	400	400	400	400	400	400
—reserve mode	270	270	270	270	270	392	392
O_2 emergency supply (manually activated), kg/h	1	2	2	2	2	2	2
SS pressure during emergency O_2 supply automatic activation, hPa	220	220	220	220	220	270	270
Onboard system		BSS-1	BSS-2	BSS-2M	BSS-2M	BSS-2M	BSS-4

[1] Without refilling or replacement of consumables (total time of two cycles was five hours).

[2] Including two SAFER parameters.