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Human Spaceflight Accidents: The USSR/Russian Space Program

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Definition

As the initial leaders in space flight, both unmanned orbiters and manned orbital flight, the Soviet Union pioneered many aspects of space

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exploration. With the continuing experience, independently and with international collaboration, the further efforts of the Russian Space Program contributed to space station development and extended duration human orbital flights. Several accidents and serious mishaps in their program occurred and are summarized.

Overview

The former Soviet Union, now Russia, was the first country to send a human into orbit when Yuri A. Gargarin launched and successfully completed one orbit in the Vostok I spacecraft on April 12, 1961. After the early success of the US lunar program, the Soviet Union switched priority for their human space program to space stations in Low Earth Orbit (LEO) Oberg (1981). They quickly set long duration records. As of 2015, 14 humans, all Russian cosmonauts, have cumulative spaceflight in LEO over 500 days, and four cosmonauts have single mission duration spaceflight records over 1 year (Valery Polyakov – 438 days, Sergei Avdeyev – 380 days, Vladimir Titov – 366 days, and Musa Manarov – 366 days). Because of the long duration experience, they also accumulated significant spaceflight incidents and close calls. As of early December 2015, in addition to the non-cosmonaut spaceflight participants carried into space by the Russians, the USSR/Russian spaceflight experience has had 120 cosmonauts who have flown 256 flights and accumulated 25,231 days in space and 53.5% of the 47,195 total days of humans in orbit. A number of serious accidents are reviewed.

Launch Pad Issues

Soyuz T10A Launch Abort

Soyuz T 10 A launched at night on September 26, 1983, at Baikonur cosmodrome with Cosmonaut commander Vladimir Titov and flight engineer Gennady Strekalov. It was Strekalov's third and Titov's second spaceflight. About 90 s before launch, a fuel valve failed to close and a fuel leak ensued followed by a fire from an electrical spark. Due to the rapid spread of the fire, the emergency detection system onboard the vehicle, which would ordinarily have initiated the launch escape system, failed. The fire continued to grow. The flight controllers recognized the situation and initiated the launch abort, but this took 10 agonizing seconds, as it required two controllers in separate locations, to simultaneously activate the launch abort switches. On activation the Soyuz launch escape system, the Descent Module with the crew inside is separated from the Instrumentation Module, which remains with the rocket below. The launch escape motors generating 176,000 pounds of thrust, fire, lifting the Orbital and Descent Modules to a height of 1–1.5 kilometers at 14–17 G's of acceleration. As the capsule reaches apogee, four paddle-shaped stabilizers deploy and the Descent Module is pyrotechnically severed from the upper structure with the launch escape rocket and the Orbital Module and falls free. Its parachute deploys and lands in the normal manner about 4 km from the launch site. The crew survived without significant injury and the launch pad burned for 20 h.

Ascent Issues

Soyuz 18 Ascent Breakup (Third Stage Launch Abort)

On 5 April 1975, Soyuz 18–1 lifted off from Baikonur Cosmodrome with Cosmonaut commander Oleg Makarov and flight engineer Vasili Lazarev for a planned rendezvous with the space station Salyut 4. Five minutes into the flight during second-third stage separation, and after the Launch Escape System was jettisoned at 160 sec, the third stage ignited but failed to separate from the second stage due to pyrotechnic failures. Vibrations prior to second-third stage separation cut wires that initiated the pyrotechnic separators. The crew immediately recognized the off nominal condition with loss of attitude control, but flight controllers in mission control did not have real time telemetry and hesitated to initiate an abort command. With the vehicle deviating from the flight path, mission control finally commanded the Soyuz to separate at 192 km distance. The crew in the Descent Module sustained a ballistic reentry of 20.6 + Gx. The capsule landed in western Siberia near the Chinese border on a mountain range. The capsule started to tumble down the mountain but fortunately the parachute snagged a tree before going over a cliff and the crew was discovered by local citizens an hour later. The total flight duration was 21 min and 27 sec. Lazarev suffered internal injuries from the reentry and landing and never flew again.

In Flight Issues

Combustion and Toxic Atmosphere Events

Combustion events on Russian spacecraft occurred on Salyut 1 in 1971, on Salyut 6 in 1979, on Salyut 7 in 1982, and on Mir in 1994 (Perry 1974). Two notable and well documented combustion events occurred during the period that NASA flew astronauts on Mir. Seven NASA astronauts flew 1–5 month missions from 1995 to 1997 on the NASA Mir Phase 1 program Portree (1995). On February 24, 1997 a solid fuel oxygen generator (SFOG) ruptured and ignited, and on February 26, 1998 overheating of an atmospheric revitalization exchange bed led to combustion. The Mir core module (base block) was launched in 1986, with 3 additional modules added over the next 3 years. Oxygen was generated onboard Mir by electrolysis which converted water into hydrogen (which was dumped into space) and oxygen. The two **Mir Elektron electrolysis** devices, powered by electricity from the solar arrays, provided adequate oxygen for three crew. During crew transfers when there were up to six crew on board, supplemental oxygen was provided by Lithium Percholorate (LiCLO4) candles which chemically stored oxygen which exothermically released (up to 750 °F) when the SFOG candle was ignited. One SFOG candle provided enough oxygen for one person for one day. SFOGs are used on emergency oxygen systems on commercial airliners. Inadvertent activation of SFOGs resulted in the ValueJet 592 airline mishap in 1996 with loss of all occupants. Jerry Linenger, the fourth NASA-Mir astronaut, was onboard when the SFOG canister protective container ruptured after the candle was lit. The SFOG unit was in the Kvant-1 module and within a minute of the fire visibility was reduced to an arm's length, and smoke filled the station within 2 min. The crew donned masks within 2 min. Space station commander Valery Korzun used three fire extinguishers to extinguish the fire, and he sustained second degree burns on his extremities (Trial by fire 2011). The fire burned for 90 s by the Russian account, but Linenger estimated it lasted 14 min. There were six crew on board and the fire blocked access to one of the Soyuz capsules so evacuation during the fire was impossible for three crew. The crew wore oxygen masks for a day and particle filter masks for 2 more days. The Atmosphere Revitalization System was able to remove combustion products to acceptable levels within 32 h. Grab sample containers were obtained 3 h after the fire and later analyzed and showed no formaldehyde, but benzene was present and carbon monoxide (CO) was 5.2 ppm in the Kvant-1 module which was below the limit of the 24 h Spacecraft Maximum Allowable Concentration of 20 ppm, probably because the oxygen-rich fire produced very little CO (Macatangay and Perry 2007).

Toxic Environment

During the late 1990s aboard the Mir space station there were repeated leaks of the **ethylene glycol heat-exchange fluid**. The vapors caused mucosal irritation in the crewmembers and if a sizable amount of the fluid contacted the face, the eyes became extremely irritated. Leaks occurred primarily in the Kvant module where the highest concentrations remained. Once a leak occurred the fluid lodged on cooler, often inaccessible surfaces, and remained there indefinitely. Ethylene glycol entered the water-recovery system and its removal was problematic. Another moderate pyrolysis event occurred in 1998 aboard Mir about 1 year after the solid fuel oxygen-generator fire. Although this was a less significant combustion event; it was more significant toxicologically. An inadequately cooled filter was put back into the trace-contaminant removal system and resulted in a burned cellulose filter which released a small amount of smoke. Hours later, the crew developed headaches and nausea. An experimental monitor for CO was aboard. It showed 400 ppm, which was confirmed in a grab sample that was analyzed on the ground later. The blood carboxy-hemoglobin level was estimated to be as high as 40%, which explained the symptoms, and peaked 5 h later.

Depressurization/Loss of Vehicle Control

Progress Capsule Collision with Mir Space Station

On 25 June 1997, while the Mir Commander was performing a manual rendezvous and docking of the Progress 234 re-supply ship with the Mir space station, a collision occurred which resulted in a depressurization and loss of attitude control tumble (Holland 2002; Foale 1999; Ellis 2000). There was one American astronaut on board – Michale Foale. The depressurization required urgent crew actions to isolate the damaged module and prepare for emergency evacuation on the Soyuz capsule. A number of human factors were implicated in the mishap. The normal automated docking system (Kurs15) was replaced with a manual system called TORU (Teleoperated Rendezvous Control System). Although the crew was trained on the system, they were not proficient as it had been 4 months since training. On 4 March 1997, 3 months prior to the actual collision, the Commander (Tsibliyev) had attempted a manual TORU docking with the Progress M-233 and had barely missed the Mir space station by 200 meters after the display screen that provided visual cues went blank. On the M-234 docking attempt, they thought that the rendezvous radar had interfered with the video display signal, so to avoid interference they shut the radar off, which consequently removed tracking closure range and rate information. In addition, the video image of Mir was difficult to acquire as the Progress was above Mir and the Earth below. With no range or rate information, the two other crew had to visually acquire the incoming Progress M-234 capsule from portholes and obtain range and closure rate with handheld laser rangefinders, which was extremely difficult and required frequent shifts to different portholes. The crew schedule had been slam shifted and they had inadequate sleep. Despite crew complaints, the Russian Mission Control Center overrode crew concerns about fatigue and lack of proficiency. The absence of telemetry data led the crew to misjudge the spacecraft's speed and position. In addition, the docking procedures were flawed, as the preplanned braking maneuvers were insufficient to slow the spacecraft's momentum. Although Mir was visible on the docking display, it was not acquired visually by the crew at the portholes until 90 s before the final docking time. The approach had to be faster (meters rather than centimeters/second) than usual because the lack of range and rate data resulted in a higher drift rate. A standard closure rate is 0.1% of the range, i.e., 1 km range should have 1 m/s closure, 100 m range should have 10 cm/s closure rate, 10 meter range should have 1 cm/s closure. Orbital mechanics further determined that the rendezvous approach from above (higher orbit) resulted in a faster closure rate. When the Progress was finally in visual range, the crew realized that braking thrust would be insufficient. Lazutkin saw the Progress suddenly emerge from behind one of Mir's solar arrays and warned the commander. With Tsibliyev now urgently aware of the closeness of Progress, he fired the braking rockets, which did little to slow the high closure speed of 3 m/s. The Progress collided with a solar array on the Spektr module, causing a leak near the solar array attachment point, and resulting in the entire space station tumbling. The crew immediately felt the depressurization in their ears and heard a loud hissing sound. The immediate concern was to seal the leaking Spektr module. To close the hatch the crew rapidly disconnected wire bundles and even cutting wires, including powered bundles to the station computers. With the station tumbling the solar arrays were no longer collecting adequate power and as the batteries ran down, the station computers went off line and the attitude control moment gyros started to spin down. Power to the Soyuz capsules, the crew lifeboat went off line. The Soyuz did not have the uplinked state vector for their Inertial Measurement Units to be calibrated for a reentry. The crew were able to finally close the hatch 11 min after the collision, and were able to maintain a 690 mmHg pressure, down from 760 mmHg (1 atmosphere) originally. Procedures call for abandoning the station at 550 mmHg. The crew were finally able to regain attitude control by firing thrusters to counter the spin by trial and error over the next several hours.

Extravehicular Activity (EVA) Incidents

Extravehicular activity represents one of the most dangerous endeavors for spaceflight crew (Shayler 2000). On the very first spacewalk on 18 March 1965, Alexi Leonov could not reenter the inflatable airlock due to immobility from the suit pressure (5.87 psi). This necessitated him deflating the suit to 3.67 psi to acquire enough mobility for ingress. The view of space during a spacewalk can be captivating, even spellbinding. One such life-threatening moment happened for rookie cosmonaut Yuri Romanenko during the 1978 Salyut 6 mission with Georgi Grechko. During the spacewalk, Grechko was outside and Romanenko was in the airlock monitoring progress. Romanenko stuck his head out of the airlock and drifted out. Grechko realized the safety line was not attached, and as Romanenko drifted by, Grechko grabbed the safety line and retrieved him. Compounding the problem, on airlock ingress they had difficulty getting the airlock to depress to vacuum. Valeri Ryumin's diary from his mission on Salyut 6 described his 15 August 1979 spacewalk as "You're out of your mind, I was telling myself, hanging on to a ship in space, and to your life, and getting ready to admire a sunset." In 1982 on Salyut 7 a tool pressing on the wrist ring caused hand numbness, and in 1984, on Salyut 7 a suit experienced a fan failure and a crew had wrist injuries. In 1991 on Mir, an Orlan suit heat exchanger ran out of water, resulting in helmet fogging requiring the other EVA crew to guide the cosmonaut back to the airlock. In 1993 on Mir, an EVA was terminated due to Orlan cooling failure and another EVA was terminated when an O2 flow pump failed.

Medical Incidents

Gontcharov et al. (2005) summarized medical issues during the six NASA-Mir flights from March 14, 1995 to June 4, 1998. Seven US astronauts flew with 6 Mir missions and worked with 12 Russian cosmonauts during that period (McDonald 1998). The medical incidents most frequently seen were small traumatic injuries to the skin and mucous, membranes and fluctuations in cardiac electrocardiograms (Fritsch-Yelle et al. 1998). The skin injuries were often related to spacewalks or spacecraft chemical leaks. Immune function may have affected mucous membranes.

Medical Evacuation/Early Mission Termination

Medical events have occurred in space, and these have affected mission objectives. Indeed, medical evacuation from space has occurred three times, the first in 1976 for intractable headaches following a combustion event, again in 1985 for urinary infection, and most recently in 1987 for a cardiac irregularity.

Soyuz 21/ Salyut 5 Toxic Environment Event

Soyuz 21 launched from the Baikonur Cosmodrome on 6 July 1976 with Boris Volynov (Commander) and Vitali Zholobov (Flight Engineer) and finally docked with Salyut 5 the following day on July 07, 1976 after a failure of the attitude control system on the previous day's rendezvous. The crew was exposed to acrid odors apparently caused by nitric acid fumes leaking from propellant tanks. There were also reports the crew didn't follow their exercise program and were sleep deprived. Mission psychologists felt there were "interpersonal issues" between the crew. Vitali Zholobov had space motion sickness as well as the aforementioned psychological issues. The crew returned on day 49 of a planned 54 day mission. Because of the early return, the recovery conditions were not optimal, and included strong winds, which caused uneven firing of the braking rockets, resulting in a hard landing at night.

Soyuz T-14/ Salyut 7 Urinary and Prostate Infection

On 17 September 1985, Soyuz T-14 docked with the Salyut 7 space station carrying Vladimir Vasyutin, Alexander Volkov, and Georgi Grechko. Eight days later Vladimir Dzhanibekov and Grechko left the station and returned to Earth after 103 days on Soyuz T-13. Vladimir Vasyutin was the Commander of the Salyut 7 space station for part of the Salyut 7 EO-4 mission. Vasyutin fell ill soon after arriving at the station and was unable to perform his duties as station commander. The mission was originally scheduled for a 216 day stay, but his illness forced an early mission termination. The illness was probably prostatitis, and he had pain and a fever as high as 104 degrees F. Savinyikh, Vasyutin, and Volkov returned to Earth on 21 November 1985 after 65 days. Vasyutin spent a month in hospital on return to Earth. This did not have an effect on his career as he went on to be a Lieutenant General in the Soviet Air Force until he came down with cancer and retired.

Soyuz TM-2/ Mir EO-2 Space Station Cardiac Dysrhythmia

Aleksandr Laveykin flew on the first part of the long duration expedition Mir EO-2 as Flight Engineer, and launched and landed on Soyuz TM-2. The mission was launched on 5 February 1987 and he was supposed to return in December 1987. Laveykin was a backup for this mission and replaced the prime crew (Alexandr Serebrov) when Serebrov was medically disqualified before the flight. Laveykin performed a strenuous EVA and developed a cardiac dysrhythmia that persisted for several days before returning to normal. The dysrhythmia recurred and mission control recommended he return before the planned December 1987 return date. He was replaced by Aleksandr Aleksandrov and returned on 30 July 1987 having spent 174 days 3 h 25 min in space. He was later returned to flight status.

Medical evacuation was in process on three other occasions when the medical condition stabilized or resolved. A Russian cosmonaut developed a dental abscess which was treated with analgesics for 10 days, and an evacuation was planned but the symptoms resolved. Another Mir cosmonaut was transiting an unlit module when his head went into a liquid ball of ethylene glycol that had leaked out and was suspended in microgravity. He developed facial and upper airway contact dermatitis, and deorbit was being considered when the NASA astronaut, physician, Norman Thaggard was able to treat him on orbit. The third near evacuation was a cosmonaut developed acute abdominal pain (suspected appendicitis) putting a deorbit plan in motion. However, the kidney stone passed.

Psychological Issues

The first Salyut 7 crew, Anatoli Berezovoy and Valentin Lebedev, arrived on Soyuz T-5 on 13 May 1982 and remained for 211 days until 10 December 1982 (Zak 2015). In Lebedev's book *Diary of a cosmonaut: 211 days in space*, (1990) he described the strain with his crewmate getting on each others' nerves and would maintain their distance in the space station and not speak to each other for days. John Blaha, aboard Mir for 4 months in 1996–1997, began experiencing fits of anger, insomnia, and withdrawal, exacerbated by an overly demanding workload. "He was hurting," Linenger wrote in his book *Off the Planet* (2000) and commented "He was, in essence, depressed." Blaha attributed his depression to isolation and language difficulty interfering with crew coordination. With a reduction in workload and improved support from mission control, his mood improved. Stress from the fire aboard Mir led Jerry Linenger himself to become more withdrawn and he discontinued voice communications with mission control when he could not get adequate communication with his family. As noted in Burrough's book about Mir, *Dragonfly*, (1998) "Linenger's voice is high−pitched and shrill; he sounds as if he is on the verge of some kind of breakdown" (For more info see Kanas et al. 2000, 2007).

Reentry Issues

Reentry anomalies have occurred frequently and are often due to vehicle configuration or faulty separation from modules (Hall and Shayler 2001, 2004). Anomalies in the crew cabin environment during descent have resulted in death and serious injury. Landing and post-impact issues also have occurred. These include hard impact injuries, and injuries that have been the result of an inability of rescue forces to reach a crew in a timely fashion.

Soyuz 11 Mishap

Soyuz 11 launched from Baikonur Cosmodrome on June 6, 1971 with three crew (Georgi Dobrovolsky the commander, Vladislav Volkov the flight engineer, and Victor Patsayev the research engineer). They were the first crew to live and work on a space station, Salyut 1, for 22 days, after the Soyuz 10 crew was not able to dock. The original 30 day mission was truncated after a combustion event and the main objective of the solar telescope was cancelled due to technical issues. The crew also had problems with the treadmill which made a lot of noise and interfered with crew rest and imparted excessive vibrations to the space station. The flight crew had been the backup crew until one of the prime crew had a medical issue just before scheduled launch (Siddiqi 1996). They had not had extensive team building, and that, coupled with the stress of the fire, resulted in some crew interpersonal conflicts during their stay. Volkov, who had flown in space before, had tried to override the decisions of Dobrovolsky, the commander. Mission control intervened to resolve the dispute regarding abandoning the station due to the fire. Prior to undocking, the Soyuz 11 crew had a warning light indicating a hatch seal problem between the Orbital Module and the Descent Module. Troubleshooting led to the hatch sensor being overridden. After undocking from Salyut 1, the crew initiated the deorbit burn. Approximately 723 s after the nominal 187 s deorbit burn, the descent module with the crew inside jettisoned the orbital module and the service module, according to plan. Twelve pyrotechnic cartridges fired to separate the orbital module from the descent module. An anomaly occurred when the pyrotechnic detonators fired simultaneously instead of sequentially, resulting in a higher than normal vibration jolt. The shock and vibration from the pyrotechnic discharge caused the pressure equalization valve to release a seal at 168 km altitude (104 miles/550,000 ft) instead of nominally opening at a much lower altitude (4 km). The equalization value, with a 35 mm orifice, would equilibrate internal cabin pressure with the outside ambient pressure so the hatch could open after landing. The crew would have immediately noticed a leak from a caution and warning display "Leakage," an accompanying audio alarm, popping ears and a hissing noise. They may have thought it was from the front hatch which had shown a transient problem during crew ingress and hatch closure prior to undocking from the Salyut (Ivanovich 2008). When that hatch was not the problem, the crew turned off the radios while they attempted to locate the leak. The leaking valve was under their Kazbek crew couch and they tried to close it manually. Two minutes after the start of the leak, the pressure had dropped to zero and the crew were unconscious from hypoxia and ebullism (water vapor gas bubbles). Dobrovolsky was found tangled in his waist straps. Patsayev was found with a bruised hand which may have resulted from his attempt to manually close the isolation valve, which required multiple turns of the valve stem. With the equalization valve still open, the pressure loss was gradual and steady and the cabin was fully depressurized in 212 s (3 min 32 s). Prior to the orbital module jettison, the pressure in the descent module was 915 mm of mercury (normal) and 115 s later the pressure had dropped to 50 mmHg and was still dropping. By 935 s after retrofire, the cabin pressure was zero and remained there until 1640 s after retrofire when the pressure began to increase as the spacecraft descended to the upper atmosphere. The cosmonauts were exposed to vacuum for about 700 sec. At orbital module separation, Volkov's pulse was 120, Patsayev's was 92–106, and Dobrovolsky's was 78–85. On previous missions, heart rate average for cosmonauts at retrofire was 120, with max of 160 seen on Tereshkova's flight. Seconds after module separation, with crew aware of the leak, Drobrovolsky's pulse was 114 and Volkov's was 180 and their respiratory rates had tripled. At 50 s after separation, Patsayev's pulse was 42. The electrocardiographic recordings of the cosmonauts indicated that after module jettison and depressurization, the heart rate had ceased after 80 s for Volkov, 100 s for Patsayev, and 2 min for Drobrovolsky.

Twelve minutes after the deorbit burn Mission Control waited for the crew to report successful module separation, but heard nothing. Thirty minutes after the deorbit burn an Ilyushin 14 search plane and Mi-8 transport helicopter observed the Soyuz 11 descending under main parachute and 14 min later Soyuz 11 landed in the early morning on 30 July 1971. Four helicopters landed simultaneously as the capsule touched down. The recovery forces' only call to mission control was "wait" and there were no further transmissions from them. Two minutes after landing the hatch was opened by the recovery team and the crew was seen to be unconscious. The capsule was on its side. Drobrovolsky in the middle (Commander's) seat was extracted first, followed by Patsayev in the left seat, then finally Volkov in the right seat. Drobrovolsky was still warm. Film shot during the recovery effort was later declassified and showed recovery forces attempting mouth to mouth resuscitation and chest compressions on all three cosmonauts. Two medical personnel were with each cosmonaut, performing artificial respiration and chest compressions. Cardiac defibrillation equipment was available on scene. Resuscitation efforts continued for an hour and included a heart lung machine, cardiac defibrillation, and blood transfusion. According to Dr. Levan Stezhadze, who was there, an intracardiac needle withdrew only air, not blood. The recovery team physician, Dr. Anatoli Lebedyev, examined the crew and felt that they had perished from a rapid decompression. Personal communication decades later with one crew recovery team member indicated that they did feel arterial pulsations intermittently in crew but it was unclear if this was associated with chest compressions. At the time of crew recovery, the cosmonauts had been lifeless for 30 min, and had spent over 11 min in vacuum. The mishap investigation revealed that the attitude control system thrusters had fired to counteract the force of the gas leak and pyrotechnic powder traces were found in the pressure equalization valve. The 35 mm orifice of equalization valve had been narrowed to 10 mm as a result of the crew attempts to close the isolation valve. The spacecraft had made a soft landing and all capsule switches were in the correct positions except the radio transmitter, which was manually switched off and all cosmonauts had unfastened their shoulder straps. The two equalization valves had also not been configured correctly. Each equalization valve system actually had two separate valves, a manual and an automatic valve, and were on either side of the main hatch. Valve 1 was over Drobrovolsky's couch, and Valve 2 was over Patsayev's couch. Each of the automatic valves were in the closed position, and Valve 1 manual valve was supposed to be closed but was actually open. Presumably the crew initially looked for the leak on the main hatch, then they would have gone to close Valve 2, which was supposed to be open, but was actually closed. This would have wasted valuable time as hypoxic incapacitation ensued. Equalization Valve 1 was in close proximity to one of the pyrotechnic devices and probably was exposed to the greatest vibration shock wave. The close out crew had improperly configured the valves because they probably assumed it wouldn't matter as the valves were on either side of the main hatch and Patseyev attempted to close the isolation valve that was already closed. In an unfortunate design flaw, the manual isolation valve was a multi-turn stem valve that took a full 35 s to fully close. The delay in addressing the correct valve, and the time to actuate closure conspired to render the crew unconscious before it could be accomplished. The investigation determined that automated equalization valve had malfunctioned when the pyrotechnic vibration shock opened it, and this was the sole cause of the fatalities.

The autopsies of the Soyuz 11 crew performed several hours after the mishap on 30 July 1971 revealed multiple punctate hemorrhages of the skin, conjunctivae, and the visceral and parietal plura of the lung. There were large quantities of gas in the heart ventricles and cranial veins and dural blood vessels and extensive brain edema. Bloody foamy liquid was observed in the trachea and large bronchi. The lungs showed pulmonary edema and focal emphysema and extensive focal hemorrhages. There were massive hemorrhages in the middle and inner ear and tympanic membrane rupture. Extensive gas distention was observed in the stomach and intestines. These findings were consistent with decompression and exposure to vacuum.

Following the Soyuz 11 mishap, the Soviets required cosmonauts wear space suits during launch and reentry on all Soyuz flights (Space Safety Magazine 2013). The *Soyuz* was re-designed with increased valve reliability and shock load tolerance (Descent into the Void 2010). They also redesigned the manual isolation valve so that it could be closed quickly and easily, reduced the charge of the pyrotechnic bolts, and replaced half of the bolts with pyrotechnic/gas actuated latches.

Landing Issues

Soyuz 1 Mishap

Soyuz 1, was the first night launch of a crewed vehicle, launched from Baikonur Cosmodrome on April 23, 1967 with cosmonaut Colonel Vladimir Komarov (the first to fly in space twice). The Soyuz spacecraft was a new vehicle with only three prior unmanned test flights (all unsuccessful) and this was the first manned launch since Voskhod 2 in March 1965. The three unmanned Soyuz test flights in the 1966 and 1967 Cosmos series revealed issues with the attitude-control system and high re-entry angle, and heat shield burn through (Siddiqi 1998). There were 203 technical issues with the new Soyuz including problems with docking systems, parachutes, hatches, and environmental controls, yet the mission was approved. There was schedule pressure to commemorate the 50th anniversary of the Communist revolution and the Russians desperately wanted a spaceflight after a 2-year hiatus. The Chief Designer, Vasily Mishin, had succeeded Sergei Korolev, who died during surgery in 1966. Mishin tried to cancel the Soyuz 1 launch. The cosmonauts felt that the Soyuz 1 mission would likely kill the pilot. Yuri Gagarin, the Soyuz 1 backup pilot, and a group of fellow cosmonauts submitted a 10-page document addressing the design problems to Communist party leaders, but it reportedly was never received. After Soyuz 1 reached orbit one of two solar arrays failed to deploy, significantly reducing electrical power and necessitating an early mission termination. The undeployed solar array covered a thermal radiator which caused heat buildup affecting guidance systems. An antenna failed to deploy, leading to communication problems, and interference between the solar array and optical sensors meant loss of vehicle attitude control which prevented the one operational solar panel from recharging batteries. With the attitude control problems, Soyuz 1 was slowly tumbling and Komarov was slightly motion sick. The original plan was for Soyuz 1 to dock with Soyuz 2 and transfer two crew from Soyuz 2 to Soyuz 1 and return with Komarov on Soyuz 1. The Soyuz 2 launch was cancelled because of the trouble Soyuz 1 experienced on orbit although consideration was given to launch Soyuz 2 as a rescue mission for Soyuz 1. Komarov's fellow cosmonaut Alexei Leonov in his dual autobiography, *Two Sides of the Moon*, (Scott et al. 2004) noted that the Soyuz 1 drogue chute deployed successfully but failed to pull the main canopy out of its container. Sensors detected *Soyuz*-1's increased velocity and activated the reserve parachute. This required jettison of the drogue and main parachutes before deploying the reserve parachute. Since the main parachute was stuck in its container, the primary drogue remained attached, and when the reserve parachute deployed, the reserve became entangled with the drogue and failed to open. The crash landing killed the cosmonaut. The accident investigation found two faults with the Soyuz parachute system. The first one was a deformed main parachute that did not allow it to deploy properly. During manufacturing, the capsule was exposed to high temperatures in a thermal chamber used to polymerize a thermal protection coating. The parachute containers were unprotected during this process, allowing a hard resin polymer to build up inside the containers and formed a very rough surface which contributed to the failure of Soyuz 1's parachutes' ability to deploy. In *Challenge to Apollo*, "The most chilling implication of this manufacturing oversight," Asaf Siddiqi (2000) wrote, "was that *both* Soyuz 1 and 2 were doomed to failure." The second fault was that the drogue chute pull force was inadequate to deploy the main chute. It was calculated to require a 1500 kg/14,700 Newtons force to pull out the main parachute but actually needed 2800 kg/27,500 Newtons of force. The reserve and main parachutes were never tested together, which may have contributed to the main and reserve entanglement. The parachute container was changed from cylindrical to conical to aid in deployment. It was rumored that a larger main parachute was added in an attempt to reduce landing impact after the parachute container was designed and the parachute fit too tightly inside. There were also rumors that the parachute had not been packed right into the parachute container, which Mishin, the chief designer, had thought. The parachute recovery system chief designer, Pavel Tkachev, was removed from his position.

Soyuz 5 Hard Landing

Soyuz 5 was part of a joint two vehicle mission in which two cosmonauts successfully performed space walks and transferred to the Soyuz 4. Despite entanglement of umbilicals and the failure to mount a monitoring camera to record the transfer, cosmonauts Yevgeni Khronev and Aleksei Yeliseyev successfully completed their space walk to the Soyuz 4. During the *Soyuz 5* reentry on January 18, 1969, the Service Module failed to separate. The spacecraft sought the most aerodynamically stable position, in which its hatch was forward facing into the thermal and aerodynamic load. As the entry G forces were reversed from the launch orientation, the cosmonaut hung in the straps. Left in that attitude, the forward facing hatch would have been destroyed by the heat of re-entry. However, the Service Module finally separated, and the descent module turned around in the proper direction. At touchdown, the braking rockets failed, resulting in a 9 g hard landing in which cosmonaut Boris Volynov broke his front teeth. He remained, clothed only in his thin track suit, cold and alone in the Soyuz, for over an hour awaiting rescue from 60 km away. The parachute riser that tangled on *Soyuz 5* might have been similar to that used on the fatal *Soyuz 1* parachute failure. Had that entry problem not been enough, the cosmonauts escaped injury were on a podium awaiting Chairman Leonid Brezhnev motorcade when an assassination attempt was made against the Chairman and several honored cosmonauts.(http://www.spacefacts.de/mission/english/soyuz-5.htm).

Post Landing Issues

Soyuz 23 Water Landing

On 15 October 1976, Soyuz 23 launched from Baikonur Cosmodrome carrying Commander Vyacheslav Zudov and Flight Engineer Valeri Rozhdestvensky. Soyuz 23 failed to dock with Salyut 5 due to a malfunction in the automated rendezvous and docking system. As Soyuz 23 utilized batteries rather than solar arrays, it had limited time on orbit, which necessitated a night-time reentry and landing on October 16, 1976. The capsule came down at night in a snowstorm in subzero weather and landed in semi-frozen Lake Tenzig. Recovery crew were hampered by the severe weather and did not find the capsule until the next morning and were surprised to find the crew alive.

Summary

The USSR/ Russian human spaceflight program has contributed significantly to the human spaceflight experience and lessons learned in low Earth orbit (LEO) (Barr 2010). The main focus of the USSR/ Russian spaceflight program has been space stations in LEO focusing on technology development and science. As of the end of 2015, 14 Russian cosmonauts had cumulative spaceflight in LEO over 500 days, and four cosmonauts have single mission duration spaceflight records over 1 year duration. As of early December 2015, USSR/ Russian spaceflight experience has had 120 cosmonauts who have flown 256 flights and accumulated 25,231 days in space and 53.5% of the 47,195 total days of humans in orbit. Although the risks of spaceflight can occur in any flight phase (launch, ascent, on-orbit, reentry, landing, and post-landing), the loss of crew events in the USSR program have occurred during reentry and landing (Ocampo and Klaus 2013). Loss of mission and loss of vehicle have occurred on launch or ascent. Orbital flight risk for the Soyuz series capsules (Soyuz, Soyuz T, Soyuz TM, Soyuz TMA, Soyuz TMA-M) is four fatalities and two loss of vehicles in 127 flights as of December 2015. The loss of crew and vehicle events occurred in the early Soyuz flights, no loss of crew since 1971. Hazards of the space environment, vehicle environment, and mission architecture have affected human performance, mission success, and crew health. Following the termination of the Space Shuttle program in 2017, the Russian Soyuz vehicle became the sole means of transport of all astronauts and cosmonauts to and from the International Space Station. In 2018, the Soyuz MS-10 launch vehicle carrying a Russian cosmonaut, Aleksey Ovchinin, and an American astronaut, Nick Hague, to the ISS aborted shortly after launch. It was safely returned to Earth by its contingency abort system. It was the first failure of a Russian manned booster in 35 years, since the Soyuz T-10-1 explosion on the launch pad in 1983.

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