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historical perspective

# Historical aspects of the early Soviet/Russian manned space program

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**West, John B.** Historical aspects of the early Soviet/Russian manned space program. *J Appl Physiol* 91: 1501–1511, 2001.— Human spaceflight was one of the great physiological and engineering triumphs of the 20th century. Although the history of the United States manned space program is well known, the Soviet program was shrouded in secrecy until recently. Konstantin Edvardovich Tsiolkovsky (1857–1935) was an extraordinary Russian visionary who made remarkable predictions about space travel in the late 19th century. Sergei Pavlovich Korolev (1907–1966) was the brilliant "Chief Designer" who was responsible for many of the Soviet firsts, including the first artificial satellite and the first human being in space. The dramatic flight of Sputnik 1 was followed within a month by the launch of the dog Laika, the first living creature in space. Remarkably, the engineering work for this payload was all done in less than 4 wk. Korolev's greatest triumph was the flight of Yuri Alekseyevich Gagarin (1934–1968) on April 12, 1961. Another extraordinary feat was the first extravehicular activity by Aleksei Arkhipovich Leonov (1934–) using a flexible airlock that emphasized the entrepreneurial attitude of the Soviet engineers. By the mid-1960s, the Soviet program was overtaken by the United States program and attempts to launch a manned mission to the Moon failed. However, the early Soviet manned space program has a preeminent place in the history of space physiology.

microgravity; weightlessness; cosmonaut; artificial satellite; orbital flight; extravehicular activity

HUMAN SPACEFLIGHT WAS ONE of the great physiological and engineering triumphs of the 20th century. The history of the early United States manned space program is well known, beginning with the suborbital flight of Alan Shepard on May 5, 1961, and climaxing with Neil Armstrong's "giant leap for mankind" on the Moon on July 20, 1969. By contrast, the Soviet/Russian manned space program has been shrouded in secrecy until recently. However, much new information has now become available, and the story has many remarkable features. Although much of the information necessarily comes from secondary sources, a recent scholarly book (5) and three excellent television documentaries (11–13) contain interviews with many of the principal people, and a reasonably authoritative account has emerged.

## TSIOLKOVSKY, AN EARLY RUSSIAN SPACE VISIONARY

Konstantin Edvardovich Tsiolkovsky (1857–1935) was a remarkable visionary who can be considered the father of human space travel not only by Russia but the rest of the world as well. Tsiolkovsky (Fig. 1, *left*) was a young, almost deaf, mathematics teacher in a small Russian provincial town when he sketched a spacecraft design as early as 1883 (Fig. 1, *right*). He published his first article on space travel in 1895 (7). There is a splendid memorial to the Russian space program in Moscow showing the upward-sweeping trajectory of a spacecraft after liftoff, and a statue of Tsiolkovsky has a prominent place. He derived the basic equations of rocket dynamics that relate the speed of rocket flight, jet exhaust velocity, propellant mass, and the mass of the rocket vehicle. He also recognized the importance of the "orbital velocity" of ~7,900 m/s, which would allow a spacecraft to orbit the Earth, and also the "escape velocity" of ~11,200 m/s, which is the speed required for a spacecraft to escape the gravitational attraction of the Earth. He also realized that spaceflight would require liquid propellants because of their greater efficiency compared with solid propellants. However, as was the case with many early rocket pioneers, he received little acknowledgement in his lifetime.

Tsiolkovsky's extraordinary vision and imagination are illustrated in his description of the liftoff of an imaginary spacecraft (Ref. 7, p. 99). Recall that this was written at the end of the 19th century and beginning of the 20th century, when the Wright brothers were experimenting with the first aircraft.

> The signal is given; the explosion, attended by a deafening noise, starts setting off. The rocket shakes

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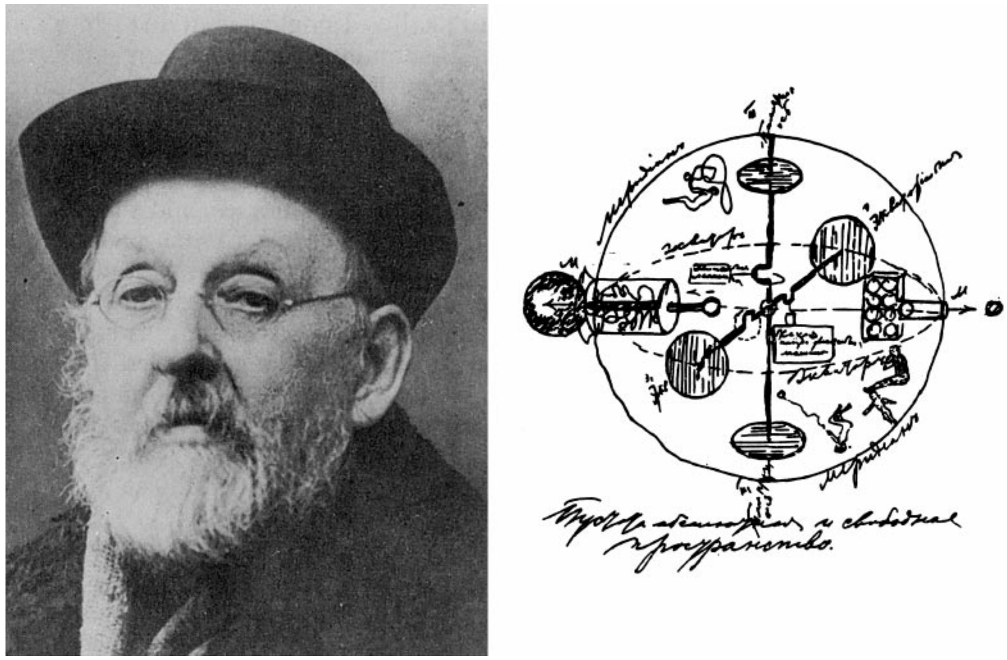

Fig. 1. *Left*: Konstantin Edvardovich Tsiolkovsky (1857–1935), an almost deaf mathematics teacher in provincial Russia but a remarkable space visionary (from Tass-Sovfoto). *Right*: sketch of a spacecraft made by Tsiolkovsky in 1883 (from Ref. 14).

> and takes off. We have the sensation of terrible heaviness. My weight has increased tenfold. I am knocked down to the floor, severely injured and perhaps have even been killed—can there be any talk of observations? There are ways of standing up to this terrible weight, but only in a, so to say, compact form or being submerged in a liquid. [Volunteers have now tolerated 30 G during water immersion (4).]
>
> Even when submerged in liquid we will hardly be inclined to observe anything outside. Be all that as it may, the gravity in the rocket has apparently increased tenfold since takeoff. We would be informed of this by a spring balance or a load gauge by the accelerated swinging of a pendulum (some 3 times faster) [the period of a pendulum is inversely proportional to the square root of G], by the faster fall of bodies, by the diminished size of droplets (their diameter decreasing tenfold), by all things carried aboard the rocket becoming heavier, and many other phenomena.

Tsiolkovsky gave an equally imaginative account of the sensation of weightlessness that he predicted would occur when the spacecraft reached orbit and the engines were turned off (Ref. 7, p. 100).

> The awful gravity that we experience will last until the explosion and the noise come to an end. Then, as dead silence sets in, the gravity pull will diminish instantaneously, just as it appeared. We are now out beyond the limits of the atmosphere at an altitude of 575 km. The gravity pull did not only diminish in force but vanished completely without a trace; we no longer even experience the terrestrial gravitation that we are accustomed to just as we accustomed to the air, though it is not at all so necessary as the latter. The altitude of 575 km is very little, it is almost at the surface of the Earth, and the gravity should have diminished ever so slightly. And that actually is the case. But we are dealing with relative phenomena, and for them there is no gravity.
>
> The force of terrestrial gravitation exerts its influence on both the rocket and bodies in it in the same way. For this reason there is no difference in the motion of the rocket and the bodies in it. They are carried along by the same stream, the same force, and, as far as the rocket is concerned, there is no gravity.
>
> There are many things that convince us of this. All objects in the rocket, that were not attached, have left their places and are hanging in the rocket's air, out of contact with anything; and if they touch something, they do not exert any pressure on each other or on the support. We ourselves do not touch the floor and can have any position and be in any direction: we can stand on the floor, on the ceiling or on the wall; we can stand perpendicularly or have an inclined attitude; we float in the middle of the rocket like fish but without any effort whatsoever, and we do not come in contact with anything; no object exerts pressure on any other if they are not pressed together.
>
> Water does not pour from a decanter, a pendulum does not swing and hangs to the side. An enormous mass hung from the hook of a spring balance does not make the spring taut—it always indicates zero. Lever scales are also useless: the balance beam takes up any position, quite irrespective of and indifferent to the equality or inequality of the weights in the pans. Gold cannot be sold by weighing its mass. Conventional ways of measuring mass cannot be employed here.

Subsequent to Tsiolkovsky's theoretical studies, several rocket pioneers were active in the 1920s and 1930s. In 1926, the American Robert Hutchings Goddard (1882–1945) launched the first liquid-propelled rocket at his Aunt Effie's farm in Auburn, Massachusetts, having previously published his classical treatise *A Method of Reaching Extreme Altitudes* in 1919 (3). However, many of his ideas were ridiculed in the New York Times and other quarters, and he largely retired from the public eye to work on his ideas in relative seclusion. Although he offered his ideas to the military in World War II, there was little interest and he worked on jet-assisted take-off devices for aircraft.

After his death, the importance of his work was acknowledged, a million dollar settlement was made for the use of his patents, and his name is perpetuated in the Goddard Spaceflight Center in Greenbelt, Maryland.

In Germany, the potential value of rockets was more clearly seen, and Herman Julius Oberth (1894–1989) formulated many of the technical problems of spaceflight, but even there many of his ideas were dismissed as fantasies. Later, he moved to Peenemünde to work with Wernher von Braun and eventually came to the United States.

**WERNHER VON BRAUN AND PEENEMÜNDE**

Any historical survey of manned spaceflight must include a section on Wernher von Braun (1912–1977) because of the critical developments in rocketry that took place in Peenemünde from 1936 to 1945. Although von Braun (Fig. 2) did not directly influence the Soviet space program, remnants of rockets were examined by Soviet engineers, and, as described below, one of the first rockets in the Soviet space program was an identical copy of the main Peenemünde rocket.

von Braun assisted Oberth in work on liquid-propelled rockets in a German rocket society in 1930; however, a few years later, the work was taken over by the army under Gen. Walter Dornberger. The group worked first near Berlin but later moved to Peenemünde in northwest Germany on the Baltic Sea where there was ample space. The most important development was the A4 rocket (Fig. 3), the first rocket to demonstrate the potential of suborbital flight, partly because of its enormous thrust and also the development of a sophisticated guidance system. In the television documentary *Spaceflight* (12), there are dramatic interviews with Wernher von Braun and Krafft Ehricke describing the first successful launch of the A4. The first toppled over to be followed by an enormous explosion, the second had better luck but went out of control, and the third streaked skyward until it was out of sight. Everybody immediately recognized

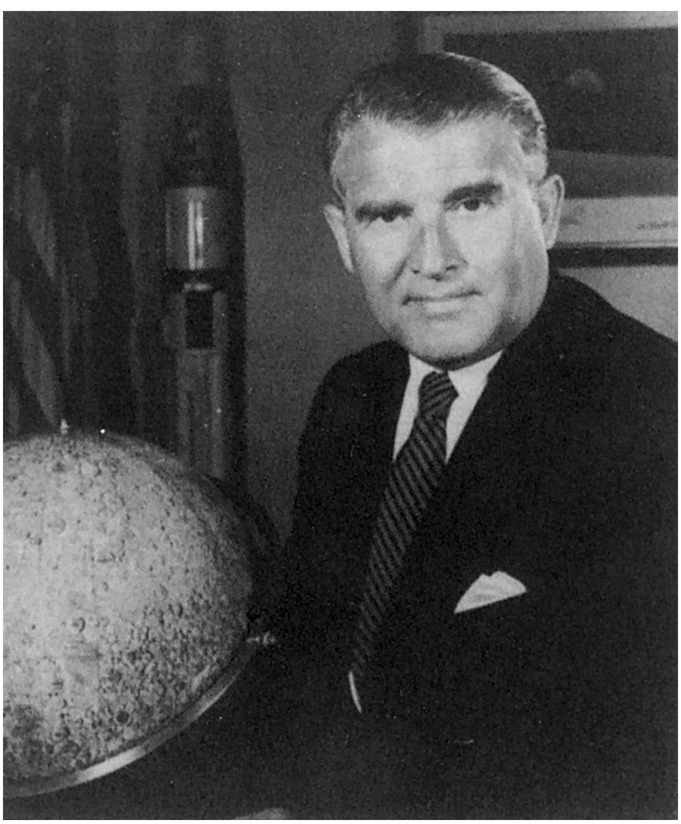

Fig. 2. Wernher von Braun (1912–1977) who developed the A4 rocket in Peenemünde, Germany during World War II. This had a great influence on both the Soviet and U.S. space programs (from Ref. 14).

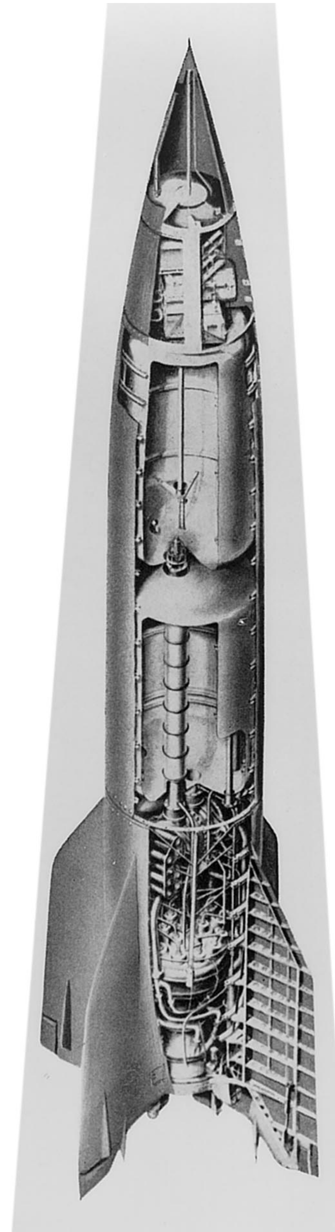

Fig. 3. A4 rocket developed by Wernher von Braun and his co-workers. This was the first successful suborbital rocket and played an important role in the development of the Soviet manned space program (from Ref. 17).

that this was the beginning of a new age when humans would enter space. Ehricke vividly describes the exhilaration of the launch team following the first successful flight.

At the end of World War II, von Braun and several others from the Peenemünde facility were transferred to the United States, where they played crucial roles in the development of the American space program. All that remained of the A4 rockets in Peenemünde was systematically destroyed, but some of the remnants were studied by Soviet rocket experts. Here is a graphic description of what Boris Chertok, one of the engineers, found (Ref. 5, p. 65)

> So I come into this hall. Several hours before me our engine man, Alexei Mikhailovich Isaev—one of the future stars of our rocket technology—was let in. I see the lower part of his body and his legs sticking out of the rocket engine nozzle, while his head is somewhere inside . . . . I approach Bolkhovitinov.
>
> "What is this?"
>
> "This is what cannot be," he replies . . . . Understand, one of our most talented aircraft designers simply did not believe that in wartime conditions it would be possible to develop such a huge and powerful rocket engine. We had at the time liquid engines of our experimental rocket planes with thrusts of hundreds of kilograms. One and one half tons was the limit of our dreams. Yet here we quickly calculated, based on the nozzle dimensions, that the engine thrust was at least 20 tons.

In fact, the A4 rocket had been redesignated as the V-2 (for Vengeance-2), and many were launched against London with terrifying results. The V-2 had a gross weight of nearly 13 tons and could carry a 1-metric-ton payload 200 km. It was the first missile to incorporate a cryogenic turbo pump and the first to use a sophisticated guidance system.

Fig. 4. Sergei Pavlovich Korolev (1907–1966) who was the Chief Designer of the early Soviet manned space program (from Ref. 14).

## SERGEI KOROLEV, THE PRINCIPAL ARCHITECT OF THE SOVIET/RUSSIAN MANNED SPACE PROGRAM

Sergei Pavlovich Korolev (1907–1966, Fig. 4) was the genius who achieved preeminence of the Soviet/Russian manned space program from its beginning to the mid-1960s. He was born in Zhitomir in the Ukraine near Kiev, and, while in his teens, he built and flew gliders. In 1926, he enrolled in the Moscow Technical High School where one of his lecturers was Tupolev, the famous Russian aircraft designer. Korolev became interested in rocketry and in 1933 was responsible for the first flight of a liquid-fuelled rocket in the Soviet Union. During 1936–1938, Korolev and his talented colleague, Valentin Glushko, used rocket engines to propel gliders.

However, in 1938, disaster befell Korolev, and the subsequent story is one that could only have occurred in the Soviet Union. He was arrested by Stalin's regime on a trumped-up charge as an "enemy of the people" and sentenced to 10 yr of hard labor. First, he was incarcerated in one of the most dreaded prisons, Kolmya, in far eastern Siberia. He spent 5 mo in the winter, digging in a surface gold mine, and many of his fellow prisoners died. Later, Korolev was moved to Moscow where he was held under house arrest in a prison for scientists known as a "sharaga," where he was allowed to do some engineering design work. This was the type of institution described by Aleksandr Solzhenitsyn in *The Gulag Archipelago* (16). One of his fellow prisoners was Tupolev. Korolev was in prison for a total of about 7 yr but was eventually released after World War II when the Soviets recognized the importance of developing a missile program and realized that he was one of their most talented rocket engineers. In 1944 Korolev was discharged from prison and his convictions were expunged, and in 1945 he was commissioned as a colonel in the Red Army. Amazingly, he then continued to work until his death 21 yr later at breakneck speed and appeared to harbor no resentment toward the regime. On the contrary, according to a sequence in one of the television documentaries (11), he told Gagarin and Leonov shortly before his death of his complete loyalty and devotion to the Soviet Union.

Initially, Korolev was asked by Stalin to build a replica of the German A4 rocket that had been developed in Peenemünde (Fig. 3). Korolev apparently argued that he could come up with a better design, but

Stalin was suspicious of technical innovation and wanted to start with something that would certainly work. Korolev complied and produced a replica of the A4 within 2 yr. He then went on to mastermind the Soviet rocket and space systems, and his successes were spectacular (Table 1). By 1957, he had developed the R-7 booster (Fig. 5), which propelled a 5-ton dummy warhead 6,400 km to Kamchatka, thus making it the world's first intercontinental ballistic missile (ICBM). This was followed by the launch of Sputnik 1, the world's first artificial satellite; the launch of the dog Laika, the first living being in space; and his most spectacular success, the launch of Yuri Gagarin, the first human being in space. Subsequent successes included the first woman in space, Valentina Tereshkova; the first three-person crew in space; and the first extravehicular activity (EVA). This was an amazing catalog of firsts.

A feature of the early Sputnik launches was their great mass (for example, that of Sputnik 3 was 1,300 kg or 1.3 metric tons), and this meant that the boosters had an enormous thrust, a realization that caused considerable alarm in the United States at the time. The R-7 booster with its five engines, each of which had four thrust chambers (Fig. 5, *right*), generated a thrust of 500 metric tons. By contrast, the Atlas booster, which was the most powerful rocket in the United States at the time, had a thrust of only 200 metric tons. Ironically, the large size of the Soviet boosters was the result of their less sophisticated nuclear technology. The ICBM was developed to propel an H bomb, which at some 5 tons was substantially heavier than the comparable weapon developed in the United States.

The military of the Soviet Union placed enormous importance on the development of an ICBM that could carry a nuclear warhead. Vassily Mishin explains in one of the documentaries (13) how the Soviet Union felt tremendously threatened because it was ringed by NATO airbases from which strategic bombers could deliver a nuclear bomb to anywhere in the Soviet Union. By contrast, the Soviet military were unable to reach the United States with a nuclear weapon, and so they saw the development of an ICBM as the only way to establish parity.

An extraordinary feature of Korolev's program was that throughout his career he was never referred to by name because of security reasons but only as the "Chief Designer." In fact, some of the cosmonauts who worked directly under him were apparently not aware of his last name. A dramatic reminder of his anonymity was when Gagarin was welcomed after his historic flight by Khrushchev in an enormous ceremony on Red Square. Korolev was nowhere to be seen because it was thought that his safety could be threatened. Only when he died in 1966 was his identity officially acknowledged, and there was subsequently a tremendous outpouring of affection by the Russian people.

Table 1. *"Firsts" in the Soviet space program attributable to Sergei Korolev*

| | |
|---|---|
| 1957 (October 4) | First satellite in space: Sputnik 1 |
| 1957 (November 3) | First living being in space: dog Laika |
| 1959 | First spacecraft to reach another celestial body: Luna 2 lands on the moon |
| 1959 | First photographs of the dark side of the moon |
| 1961 (April 12) | First human being in space: Yuri Gagarin |
| 1962–1964 | First spacecraft to reach Mars and Venus |
| 1963 | First woman in space: Valentina Tereshkova |
| 1964 | First 3-man crew in space |
| 1965 | First extravehicular activity: Aleksei Leonov |

One of Korolev's greatest achievements was the launch of Sputnik 1 on October 4, 1957 (Fig. 6). This used an R-7 booster, although the payload was only about 80 kg. Of course, Sputnik 1 created a sensation everywhere, not least in the United States, because it could be seen crossing the sky at dusk, and, by tuning into its frequency on a small radio, anyone could hear the beep-beep. It is interesting that the Soviet authorities completely underestimated the political fallout of Sputnik 1 (as related by Sergei Khrushchev) because the October 5 issue of Pravda relegated the launch of Sputnik to a small section on the front page. It was only when the sensation that the event occasioned in the West was recognized that the October 6 issue of Pravda carried the full story.

## FLIGHT OF THE DOG LAIKA, THE FIRST LIVING CREATURE IN SPACE

The events leading up to the launch of the dog Laika provide a graphic demonstration of the differences between the Soviet and United States space programs at this stage. As can be imagined, there were many delays before the successful launch of Sputnik 1, and, according to Vassily Mishin, one of the key Soviet rocketeers, the living conditions at the launch site were appallingly bad. It was therefore with tremendous relief that everybody connected with Sputnik 1 looked forward to a period with their families in a more comfortable environment after the successful launch. However, this was not to be. To the chagrin of the launch team, they were immediately ordered back to work. Cosmonaut Grechko relates the events as follows (Ref. 5, p. 132)

> I heard this from Korolev himself with my own ears. After *Sputnik I* Korolev went to the Kremlin and Khrushchev said to him, "We never thought that you would launch a sputnik before the Americans. But you did it. Now please launch something new in space for the next anniversary of our [October] revolution."
>
> The anniversary would be in one month! I'll bet that even with today's computers nobody would launch something into space in one month. It was, I think, the happiest month of his [Korolev's] life. He told his staff, and his workers, that there would be no special drawings, no quality check, everyone would have to be guided by his own conscience. And we launched on November 3, 1957, in time for the celebration of the Revolution [because of a calendar change, the October revolution is now celebrated on November 6].

The payload of Sputnik 2 included the mongrel dog Laika, who was placed in an environmentally controlled chamber immediately below a replica of the Sputnik 1 sphere (Fig. 7). The physiological vari-

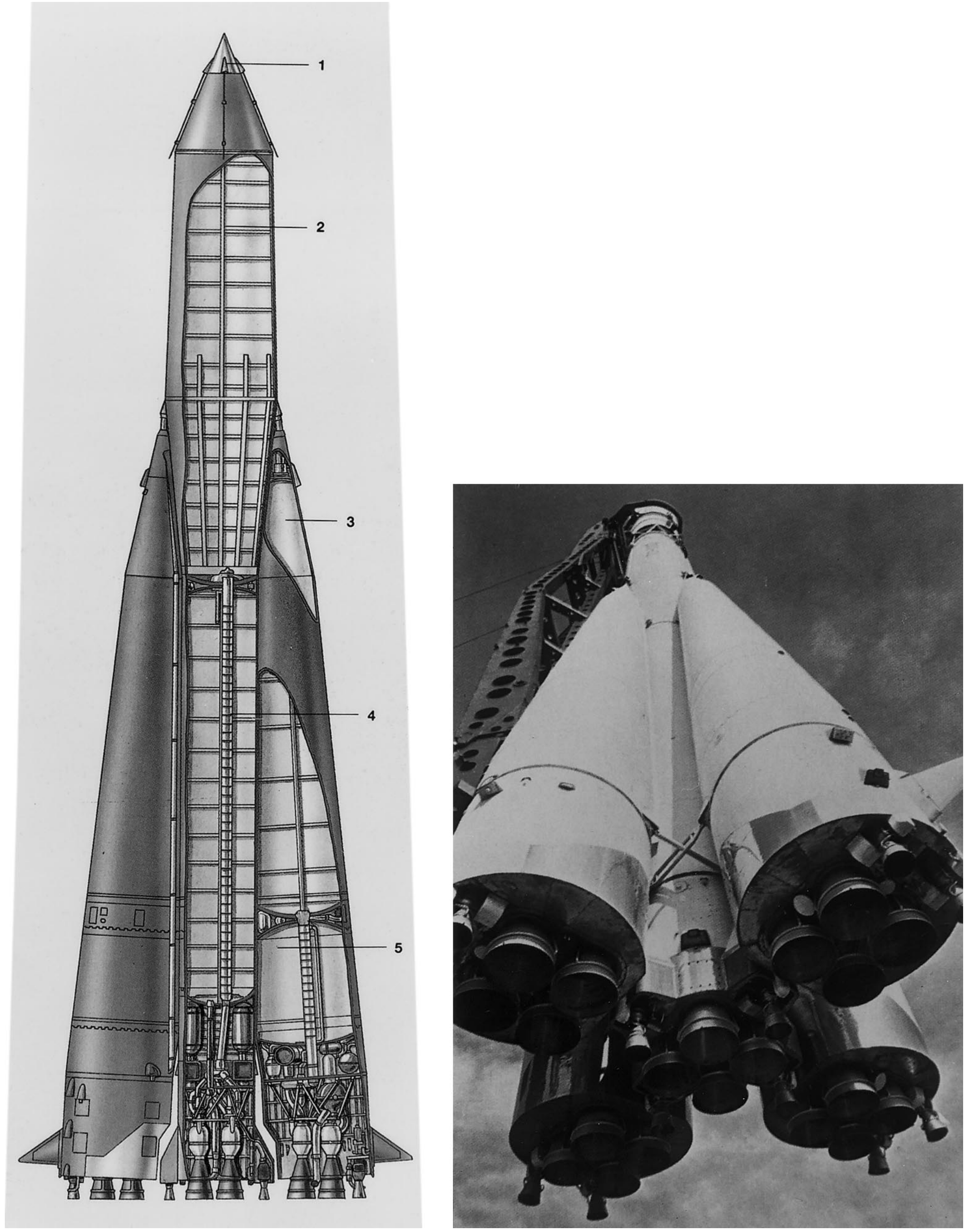


Fig. 5. Two views of the R-7 booster designed by Korolev and others that put Sputnik 1 and many other firsts into Earth orbit. This had 5 clustered engines each with 4 thrust chambers. Modifications of this design are still used (from Refs. 1 and 9).

ables that were monitored and telemetered back to Earth included electrocardiogram (chest lead), blood pressure, respiration rate, and motor activity (15). Food was automatically delivered twice a day. The heart rate was 103 beats/min before launch and increased to 240 beats/min during the early acceleration. However, after 3 h of weightlessness, it was back to 102 beats/min. Because the orbit of the spacecraft was very elliptical, the solar irradiation was higher than planned and the environmental chamber overheated. Apparently, no engineering work had been done on the payload of Sputnik 2 until after Sputnik 1 went up a month before. It is almost unbelievable that such a complicated payload could have been put together in such a short time, and the triumph emphasizes the resourcefulness and the fly-by-the-seat-of-the-pants attitude of the Soviet designers in contrast to the much more cautious attitude of NASA, which came into being about 10 mo after the launch of Sputnik 1.

The flight of Laika was followed by the launch of Sputnik 3, which contained a large load of scientific instruments to measure upper atmosphere phenomena. Actually, Sputnik 3 required two attempts because the first launch on April 27, 1958, failed as a result of problems with a rocket engine. The successful launch took place on May 15, 1958, and, although its payload was devoted to atmospheric physics, there was an interesting sidelight that is relevant to manned spaceflight. Part of its instrumentation was designed

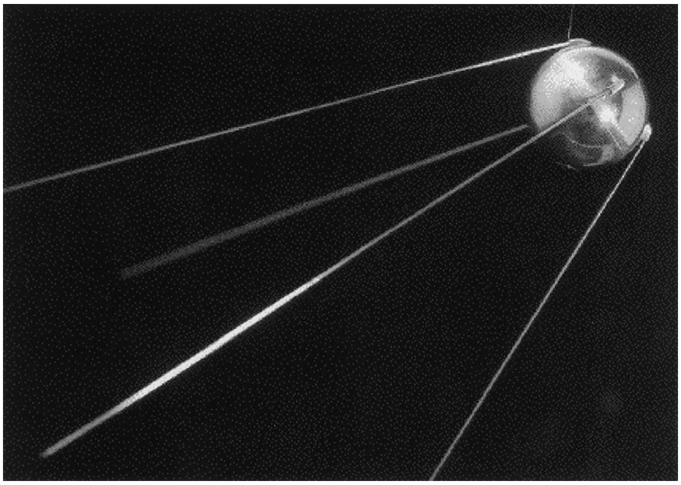

Fig. 6. Sputnik 1, the first artificial satellite. Its total weight was just over 80 kg (from http://www.fht-esslingen.de/telehistory/sputnik.html).

to map the radiation belts in the atmosphere, but the experiment was unsuccessful because of the failure of a tape recorder. In fact, Sputnik 3 detected high levels of radiation, but it was not possible to say whether these were local or distributed in a belt around the Earth. It was left to the United States satellite, Explorer 1, with only one-sixth the payload weight of Sputnik 2 to discover the Van Allen radiation belt as it is now called. This intense region of radiation is of considerable importance to astronauts and cosmonauts: it is avoided so that radiation doses can be limited to acceptable levels and it partly determines the altitude of orbiting manned spacecraft.

## FLIGHT OF YURI GAGARIN, THE FIRST HUMAN BEING IN SPACE

The large amount of information now available about Sergei Korolev makes it clear that, from the outset, his main objective was to launch a human being into space and, if possible, have him or her reach the Moon or even Mars. Korolev was a remarkable visionary! However, in practice, the Soviet space program was dominated by the military who recognized its importance for delivering nuclear weapons. Sergei Khrushchev (son of Nikita Khrushchev) tells the story that Korolev met Premier Khrushchev and told him that he wanted to launch the first artificial satellite (Sputnik 1). "What's that?" asked the Premier, and "will it interfere with the military program?" On hearing Korolev say that it would not, he gave the assent. However, the documentaries make it clear that there was considerable tension between Korolev and the military when he successfully pursued his manned space program.

Actually, it was obvious to outsiders that when Korolev launched Laika and then Sputnik 3 with its 1.3-ton payload, he was leading up to the launching of

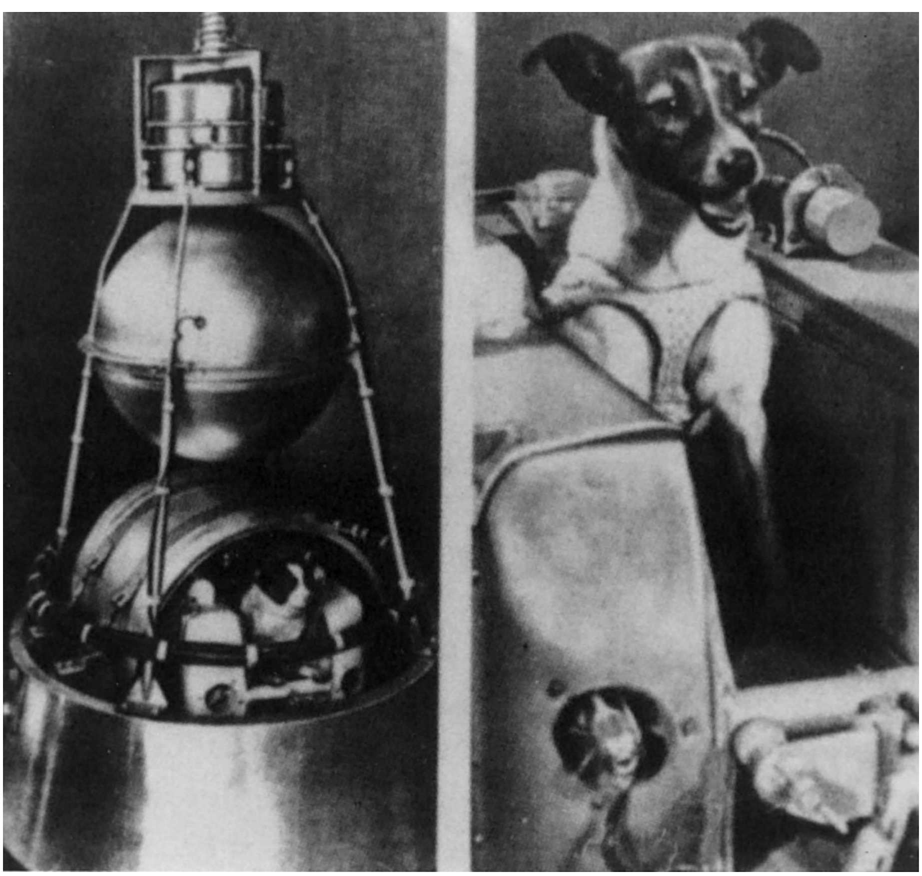

Fig. 7. The payload of Sputnik 2, which included the dog Laika, the first living being in space. The compartment for the dog is below a replica of Sputnik 1 (from Ref. 1).

a human being. Alexei Leonov in one of the documentaries describes how Korolev met with the cosmonauts in training and chose Gagarin (Fig. 8) apparently more because of his personality rather than objective data. All of the 20 or so cosmonauts in training were pilots of fighter aircraft, as was the case with the 7 astronauts who made up the U.S. Mercury team.

Yuri Alekseyevich Gagarin (1934–1968) was launched into low Earth orbit by means of an R-7 booster on April 12, 1961. According to the documentaries, some people in the launch team had serious misgivings about the proposed flight because there had been a number of rocket failures. For example, there was an explosion of a ballistic missile at the launch site only 6 mo before that killed ~165 people, including a number of leaders in the space program. Before Gagarin's flight, much thought had been given to the effects of spaceflight on the human body and extensive research on the effects of weightlessness on various animals had been carried out by the Institute for Biomedical Problems in Moscow under the directorship of Oleg Georgievich Gazenko (1918–) using free-fall from high-altitude balloons. This institute was responsible for various aspects of human environmental physiology, including space, high altitude, and diving (2). In fact, there was some crossover between these disciplines in part because of the Russian belief in cross-adaptation. The thrust of this was that adaptation to one environmental extreme improved the ability of the body to withstand another environmental stress. For example, it was believed that acclimatization to high altitude improved human tolerance to very high accelerations. The Soviets were just as macho as anybody else in this area; in one of the television documentaries, Alexei Leonov proudly states that he has tolerated 14 G. Of course Gagarin's flight produced a sensation throughout the world, but many of the details were unknown until recently. As an example, it was assumed for a long time that Gagarin had landed in his space capsule, and one of the television documentaries implies this. However, it is now known that Gagarin ejected from the spacecraft at an altitude of ~7,000 m and came down by parachute.

Fig. 8. Yuri Alekseyevich Gagarin (1934–1968), who was the first human being to enter space.

Excerpts from Gagarin's personal account of his flight are now available (Ref. 5, p. 170–175), and they make fascinating reading. The acceleration during the launch exceeded 5 $G_x$ (eyeballs in) but did not prevent Gagarin from communicating with the ground. Once in orbit he described the appearance of the Earth and the unexpected complete blackness of the sky as has now been done many times since. He had no problem with eating or drinking. During the flight (duration of 1 h and 48 min), a number of physiological variables were monitored, including electrocardiogram and chest movements by pneumography. A television camera also recorded the cosmonaut's activities.

The main physiological variables that were monitored were the electrocardiogram and respiration rate (18). Four hours before launch, the heart rate was 65 beats/min and the respiration rate was 12 breaths/min. Interestingly, 5 min before launch, the heart rate had risen to 108 beats/min and the respiration rate to 25 breaths/min, presumably because of anxiety. One minute after the start of the launch, the heart rate exceeded 150 beats/min. At this time, Gagarin was exposed to increased acceleration forces, vibration, and noise from the rocket engines, but he reported that these sensations were easily tolerated. As the spacecraft ascended and then entered orbit, the heart rate steadily fell to about 100 beats/min. After 20 min of weightlessness, the rate had fallen slightly farther with a mean of 97 and range of 85–113 beats/min. However, the respiration rate tended to remain high so that during the period of 10–15 min after the beginning of weightlessness it ranged between 24 and 37 breaths/min. During descent after the braking rockets were fired, the pulse rate rose to 112 beats/min and the respiration rate was in the range of 25–30 breaths/min.

However, the reentry and landing did not go according to plan and here are excerpts from Gagarin's account (Ref. 5, p. 173–174)

> At precisely the appointed time the third [reentry] command was issued . . . . I felt the braking rocket kick in . . . . The braking rocket operated for exactly 40 seconds . . . . As soon as [it] shut off there was a sharp jolt, and the craft began to rotate around its axis at a very high velocity . . . . about 30 degrees per second at least . . . . I waited for the separation. There wasn't any. I knew that, according to plan, that was to occur 10–12 seconds after the braking rocket switched on. I decided that something was wrong . . . . I estimated that all the same I would land normally . . . . The Soviet Union was 8000 km long, which meant I would land somewhere in the far east . . . . I reasoned that it was not an emergency situation. I transmitted the all-normal signal with a key.
>
> The craft's rotation was beginning to slow, but it was about all 3 axes . . . . Suddenly, a bright crimson light appeared along the edges of the shade . . . . I felt the oscillations of the craft and the burning of the coating . . . . It was audibly crackling. Then the g-load began to steadily increase. It felt as if the g-load was 10 g. There was a moment for about 2–3 seconds when the indicators on the instruments began to become fuzzy. Everything seemed to go gray.
>
> I'm awaiting the ejection . . . . At an altitude of approximately 7000 m hatch number 1 was shot off . . . . I'm sitting there thinking, that wasn't me that was ejected, was it? Then I calmly turned my head upward, and at that moment the firing occurred and I was ejected . . . . without a hitch. I didn't hit anything . . . . I flew out in the seat.
>
> I immediately saw a large river. I thought that's the Volga . . . . When I was parachute training, we had jumped many times over this very site. I see that I am going to land in a plowed field . . . . The landing was very soft . . . . I was alive and well.
>
> I went up on a knoll and saw a woman and a little girl coming toward me . . . . . I saw the woman slow her pace, and the little girl broke away . . . . I began to wave my arms and yell "I am one of yours, a Soviet, don't be afraid, don't be scared, come here . . . ." I went up to her and said I was a Soviet and that I had come from space.

There is no doubt that Yuri Alekseyevich Gagarin had the right stuff!

## ALEXEI LEONOV PERFORMS THE FIRST EXTRAVEHICULAR ACTIVITY

Aleksei Arkhipovich Leonov (1934–) comes over in the television documentaries, especially in *Russian Right Stuff* (11), as one of the most engaging personalities in the early Soviet manned space program. He recounts how Korolev told him in 1962, "Any sailor on a ship has to know how to swim, and so each cosmonaut has to know how to swim and do construction work outside his vehicle in space. Now orlyonok [eaglet], put on a space suit and go through the procedures for the engineers." In fact, Leonov became the first human being to perform EVA or space walking on March 18, 1965; again, this is a remarkable example of Soviet seat-of-the-pants resourcefulness.

The spacecraft called Voskhod that was used was a larger version of Vostok in which Gagarin had been launched 4 yr earlier. For the second flight of Voskhod, it was fitted with a collapsible cylindrical airlock about 1 m in diameter and 2.5 m long with hatches at both ends. The airlock was stove-piped into the side of the spacecraft and constructed of a double-thickness rubber-like material covered with protective fabric. It was folded down like an accordion in the shroud of the spacecraft during liftoff and was subsequently expanded. This arrangement allowed the cosmonaut to enter the airlock, close a hatch in the spacecraft wall, decompress to the hard vacuum of space, and then open another hatch and emerge at the other end. The pressure suit itself was developed in only 9 mo, and it was necessary for Leonov to prebreathe oxygen for some time to washout the body nitrogen and so avoid decompression sickness (bends). The atmosphere of all the Soviet spacecraft was air at 760 Torr pressure. At the end of the EVA period when the cosmonaut was safely back in the capsule, the airlock was unfastened and allowed to drift away. It is difficult to imagine relying on such a makeshift device, but it worked. There is an unforgettable television sequence showing Leonov pushing off from the airlock and floating out into space waving his right hand while tethered by an umbilical (Fig. 9). His account in his own words is dramatic (8).

The photographs of Leonov floating alone in space provided another sensation throughout the world. However, what was not known at the time was that a crisis developed when he tried to reenter the airlock. As he describes in the documentary, his spacesuit had expanded so much that it took him 12 min of

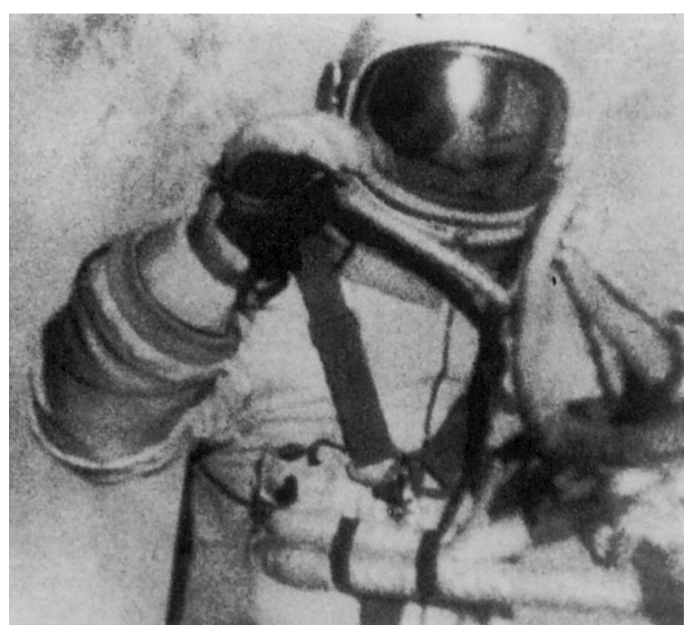

Fig. 9. Aleksei Arkhipovich Leonov (1934–) performing the first extravehicular activity or space walk (from Ref. 10).

struggle to get back into the airlock so that he could close the outer hatch. His oxygen supply was nearly exhausted; only by depressurizing the suit to some extent with a hand-operated valve was he able to reduce its volume and eventually make his way back into the safety of the capsule itself. The stress that Leonov was subjected to can be realized by the respiration rate and heart rate, which were both monitored. The respiration rate reached 26–30 breaths/min (vs. 10–15 under ordinary conditions on Earth), and the heart rate was 152 to 162 beats/min (6). Again, we have to marvel at the bravery and enterprise of these early cosmonauts.

Some people at the time thought that the EVA was something of a circus act with little practical value in space exploration. Of course, we now know that EVA plays a critical role in maintaining a space station such as Mir; in addition, the construction of the International Space Station, which is in progress at the present time, relies heavily on EVA. In fact, there will be more EVAs in the next 4 yr than in all previous years of the manned space program, although they carry an appreciable physiological risk, for example, from decompression sickness.

The resourcefulness of the Soviet space engineers in developing the collapsible airlock for the first EVA is further highlighted by a particularly colorful anecdote told to Harford by Arkady Ostashov, an engineer (Ref. 5, p. 118)

> In 1961 we had the first test of the R-9 ICBM. The test pad had two parts—a movable part attached to the missile, and a fixed part on the pad itself. The two parts were mated on the pad. When the engine was ready to start we detected a small leak of liquid oxygen between the two parts. You could see a small cloud of oxygen vapor. Voskresensky said, "Let's go to the rocket."
>
> He and I and another guy approached to make sure that the leak was small. Fortunately nobody was watching. Voskresensky pissed on the leaky joint, the liquid froze, and the joint held until ignition.

Perhaps this anecdote is too good to be true.

## SALYUT AND MIR, THE FIRST PERMANENTLY MANNED SPACE STATION

The Soviet/Russian manned space program continued its successes with the launch of Salyut 1 in April 1971, which became the world's first space station. Even more impressive was the launch of the first components of the Mir space station in February 1986. This was the first permanently inhabited space station and remained in orbit for some 15 yr, far beyond its design lifetime of about 5 yr. However, these projects will not be considered in detail here because they do not belong to the early Soviet/Russian manned space program. In fact, by the mid-1960s, the Soviet program was running into difficulties for various reasons. Korolev died in 1966, and, according to the documentaries, the loss of this charismatic leader resulted in political infighting within the Soviet space program. The Soviet program to put a human on the Moon, which was strongly supported by Korolev, foundered in part because of the enormous cost of developing a suitable booster. This was the N-1 rocket, which was approximately the same size as the Saturn V that allowed the American astronauts to reach the Moon, but its construction was plagued with difficulties, and at least one blew up on the launch pad. Although the Soviets marshaled enormous resources toward their Moon program, they could not compete with the great range of private aerospace companies in the United States. Nonetheless, the extraordinary enterprise of Korolev, in particular, and many others in the early Soviet manned space program will never be forgotten.

## APPENDIX

*Sources of Material*

Of course, a historical account like this must be derivative. However, the three television documentaries contain interviews with many of the principal people concerned, including Wernher von Braun, Krafft Ehricke, Lt. General Victor Favorsky, Konstantin Feoktistov, Lt. General Kevim Kerimov, Sergei Khrushchev, Natalya Korolev (daughter of Sergei Korolev), Sergei Kryukov, Alexei Leonov, and Vassily Mishin. The three documentaries are *1*) *Red Files: Race to the Moon*, including interviews with Leonov, Mishin, Khrushchev, Feoktistov, Natalya Korolev, etc. (13); there is a Web page with additional information at http://www.pbs.org/redfiles/; *2*) *Russian Right Stuff* in the NOVA series (11) introduced by Alexei Leonov; and *3*) *Spaceflight* by PBS (12), including interviews with Wernher von Braun and Krafft Ehricke.

In addition, the *Korolev* book by James Harford (5) is well-researched and contains many verbatim quotations from some of the most important Soviet people involved.

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