History of Rocketry and Astronautics

Proceedings of the Twenty-Fifth History Symposium of the International Academy of Astronautics

Montreal, Canada, 1991

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AAS History Series, Volume 20

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 12

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 1997

ISSN 0730-3564

ISBN 0-87703-424-9 (Hard Cover)
ISBN 0-87703-425-7 (Soft Cover)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198

Printed and Bound in the U.S.A.

Chapter 7

From the Development History of the Vostok Spacecraft[*]

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The first manned spaceflight called for a high level of reliability of the spacecraft's systems. One of the principal ways of achieving this for Vostok was the use of the simplest engineering approaches and solutions, often at the sacrifice of other characteristics (e.g. increasing the weight of the instrument section) that were not critical to assuring spaceflight safety.

The early years of the space age were a unique period in history. This was true as much of the emotion-laden atmosphere of those days, as of the technical decisions made by the designers and builders of space vehicles. While the launch, in 1957, of Sputnik was essentially the triumph of the launch vehicle—for, admittedly, the first artificial Earth satellite was in technical terms simplicity itself—putting man into outer space was a technological challenge without precedent. Yuri Gagarin's orbital flight in April 1961, a brief three and a half years after the launch of the "simplest" Earth satellite, was a spectacular achievement that captured the imagination. After all, the men of the Soviet space program had just three years in which to design and build a spacecraft, conduct many different tests and a series of unmanned spacecraft launches, in

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[*] Presented at the Twenty-Fifth History Symposium of the International Academy of Astronautics, Montreal, Canada, 1991.

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order to fine-tune the engineering solutions adopted, and to subsequently double check the high level of reliability of the spacecraft and its systems.

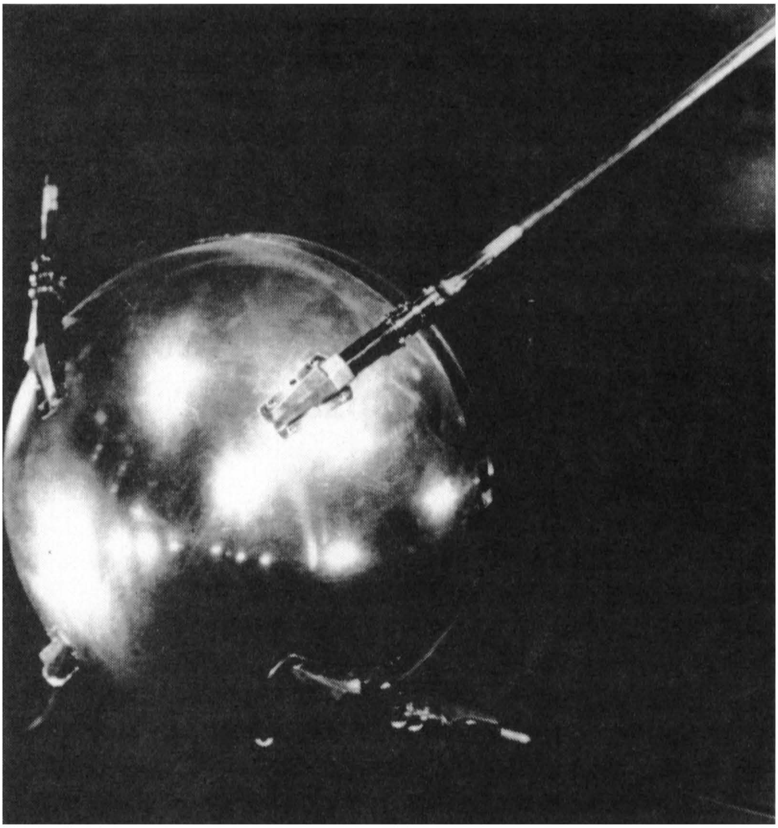

Figure 1 Sputnik-1.

Looking back today on those stirring days, many may wonder why the rush. But for those of us engaged in the Soviet space program in the late 1950s and early 1960s, the pace of the space race was not fast enough. We were all propelled by the primary motivation of eternal human curiosity and impatience. We should bear in mind that Sergei Korolev, the architect and moving spirit of the Soviet space program, and some of his closest associates, had begun work on rocket technology well before World War Two, fired by the exciting possibility of breaking the chains of the Earth's gravitational pull to emerge into outer space. The success of Sputnik One opened up, for all of us, what seemed like unlimited possibilities, not just improved modification of satellites for a variety of purposes, but also the breathtaking possibility of manned flight, and automatic probes to the Moon, Mars, and Venus. The mood was one of enthusiasm and exhilaration. We were champing at the bit, raring to go, eager to push in all directions, without delay. Sergei Korolev summed up this noble impatience well in a graphic phrase: life is so short, while so much remains to be done.

Another factor behind the rush was the spirit of competitive rivalry. We knew that our American counterparts were also making preparations for piloted space missions, and so, both "teams" across the Atlantic were rushing on to win the space race. In this situation, technical approaches and solutions to the design and testing of the Vostok spacecraft had to be consistent with minimum lead-time.

One other requirement that had to be met, perhaps the most important one, which challenged the talents of the spacecraft's developers was, for obvious reasons, absolute reliability of all the design options adopted. After all, what was being attempted was the first manned space flight in human history, and that realization lent the goal of absolute reliability special significance. In a situation where we did not have the time for prolonged testing, there was only one way to achieve maximum reliability, and that was by using the ultimate in design simplicity and basic engineering solutions. The pursuit of simplicity entailed the abandonment of what seemed like obvious and natural solutions, and it called for bold and unorthodox thinking.

The chief characteristic of a manned spacecraft, that set it apart from automatic space probes, was, of course, the safe return to Earth of its human "payload," the spaceman. It would, perhaps, be of interest to analyze this characteristic, peculiar to manned space missions, in order to assess the solutions and approaches adopted by the designers of the Vostok spacecraft from the standpoint of maximizing reliability in a minimum of time.

First, a few words about the spacecraft's capsule (descent module), which at the end of the flight separated from the instrument section and parachuted down to Earth. We knew that the spacecraft's re-entry through the lower atmosphere would generate intense heat. We also knew that reliable protection from the heat could be provided by heat shields similar to those used to protect the warheads of ICBM missiles, which were available at the time. The geometric shape of the capsule, however, proved a more difficult proposition.

From the outset, it was clear that a complex shape, similar to that characteristic of the Soyuz, Gemini, and Apollo spacecraft, was optimum for the purpose. One of the chief merits of this particular shape was the fact that it made a controlled re-entry possible. The disadvantage was that this shape required a large amount of computational research, the testing of models in wind tunnels and the development of a suitable re-entry attitude control system. All of which, especially wind tunnel testing, took time, and time was short. In this situation, we had to opt for a spherical capsule for Vostok. The aerodynamic characteristics of the sphere were sufficiently well known, while the sphere's complete symmetry ruled out lateral forces, which could distort the spacecraft's trajectory in the event of an uncontrollable re-entry. The spherical shape created drag so essential for re-entry, and this removed many potential problems. Needless to say, abandonment of the idea of a controlled re-entry and of the optimum geometric shape for the spacecraft's capsule left it with a number of inherent flaws, and it would be in order to dwell on the "price" of our decision to take the short cut.

Now, uncontrollable, ballistic descent has two major strikes against it: considerable ballistic dispersion and heavy g-forces. While today the predicted touch-down point of a returning spacecraft is always well known, and the recovery team expects it there, actual Vostok touch-down points deviated from the planned ones by as much as 100 kilometers and more. As a result, their recovery required the maintenance of unwieldy and costly ground services, whose job was made difficult, as they had, literally, to search for the landed spacecraft. The g-forces experienced by the cosmonaut on re-entry were of the order of 9-10 versus 3-4 in the case of Soyuz spacecraft. But these disadvantages, in the belief of Vostok developers, were fully outweighed by the time gained. Apart from that, the option adopted offered greater reliability, since a controlled re-entry did not rule out the possibility of failure of the re-entry attitude control system. By contrast, in the Vostok case there was nothing to fail.

A similar approach characterized the re-entry and landing system that was eventually adopted by the Vostok developers. In the "classic" scenario, the cosmonauts land inside the capsule (descent module). Its design incorporates rather sophisticated gadgetry, designed to protect the spaceman from the effects of the impact of the capsule against the ground. If the landing capsule hits rocky ground, the shock effects on the spaceman himself could be pretty severe. Therefore, suitable shock absorbers to cushion the impact are required. The development and testing of shock-absorbing systems was time-consuming, and so it was decided to borrow from aviation's experience—at a comparatively low altitude above ground the cosmonaut leaves the capsule by means of an ejector seat and goes through a familiar, well-practiced routine of separation from the ejector seat, parachute opening and ordinary landing of the type performed daily by hundreds of sky-divers. Also, with this technique it was easier to assure touch-down safety. Indeed, during descent by parachute, the cosmonaut could maneuver to pick a more suitable touchdown point and avoid having to land in a dangerous spot. While this method of landing was hardly more simple than the "classic" landing technique used today, its advantage was that it had been repeatedly tried and tested in aviation, and it did not call for prolonged research and testing. The desire to save time, and to rely on what was already available, was very much in evidence even in little things, as, for instance, during work on the design of the landing system parachute, when designers proposed developing a special, more advanced parachute for the cosmonaut. Their suggestion was rejected in favor of a standard type of parachute that had a long track record of reliability. Its improvement in other respects would have taken time, and time, as I said before, was short, while speed was of the essence.

A high level of reliability of the spacecraft's systems was achieved, not only through the use, where possible, of available technologies as was the case with the parachute. One of the effective ways of increasing the reliability margin was by reducing the number of units and components that could potentially fail and result in a dangerous emergency. One example of this approach was the use of a fixing method to hold the capsule and the instrument section together. This unit was designed to separate the two sections prior to re-entry. One obvious method was to use three or four fixing points by means of special locks that would open simultaneously on separation. However, it was obvious that failure of at least one lock would result in a serious emergency. It was clear that fewer locks would increase separation reliability for the capsule and the instrument section. That is why a bold decision was eventually adopted to make do with just one lock. The capsule and the instrument section were held together by four metal strips, which "pressed" the capsule into a special recess in the instrument section. These four strips came together in one lock, so that its opening released all four strips simultaneously to separate the capsule from the instrument section. While this method had its disadvantages, its high reliability and simplicity were self-evident.

In this context, the automatic attitude control system installed on the Vostok spacecraft taught us a useful lesson. As you well know, to initiate reentry from Earth orbit we have to fire the spacecraft's retro-rocket to change its orbit. This is normally done by deceleration—decreasing orbital speed results in gradual loss of altitude, and the capsule enters the dense layers of the atmosphere, where it is finally decelerated before touch down on the Earth's surface. The pulse imparted to the spacecraft before re-entry is technically known as "retrofire." Many space-age historians (those in the West included) have used this term rather indiscriminately and wrongly, certainly in the case of Vostok, for the simple reason that the spacecraft executed the maneuver to change its orbit prior to re-entry by anything but pure deceleration of flight speed.

The laws of celestial mechanics tell us that re-entry through the atmosphere (landing maneuver) can be executed not only by means of deceleration but also by a vertical pulse that "presses" a spacecraft to the Earth. This type of maneuver is never used, as the amount of fuel for the retro-rocket required to execute it, is four times the amount of fuel used for pure deceleration. This, of course, is an extreme case, but it is important for what follows to recognize that the "purity" of the deceleration process is not at all mandatory.

The first two test flights, in 1960, of spacecraft that preceded Vostok, carried two automatic attitude control systems: one advanced and one basic. The former responded to the Earth's infrared radiation and used sophisticated gyroscopic devices. It was this system that made it possible to fire the spacecraft's retro-rocket precisely in the right direction. This type of attitude control system is now classic, and it is used both in the U.S.S.R. and the U.S.A. The 1960 test flights showed that some of the components of such a system required improvement, i.e., they had to be fine-tuned to achieve the desired level of trouble-free operation and this took time. The tests of the second system were successful and convinced everybody of the system's high reliability through maximum simplicity of design.

The second system used the Sun to determine when to fire the retro-rocket to initiate re-entry. Now, the Sun is a large and bright enough object so that it cannot be mistaken for any other celestial body (other planets and stars) and cannot be missed. So a suitable attitude control system was developed, which directed the axis of the retro-rocket's nozzle towards the Sun, with the result that the thrust of the retro-rocket was directed away from the Sun. It is clear from this, therefore, that the resultant retro-fire received by the spacecraft was anything but "decelerant." Calculations showed that even with the Sun high above the local horizon, i.e. when the thrust of the retro-rocket has a sufficiently significant "down-pressing" component, re-entry is quite feasible. Of course, we refer to cases when the Sun was "ahead of" the spacecraft, in the sunrise phase, before its transit across the local zenith.

The "price" we had to pay for the high reliability and the time gained was pretty high: increased fuel consumption for re-entry and landing, and rather severe restrictions on windows of opportunity for launch and landing times. Indeed, launch time and flight duration had to be determined in such a way that, by the time for firing the spacecraft's retro-rocket, the Sun had to be just where we wanted it in relation to the spacecraft, namely, just ahead of it and not too close to the zenith. Even so, these disadvantages were fully offset by the advantages, above all, by the high reliability of the entire re-entry and landing system.

Our choice of this particular option for the spacecraft's attitude control system was governed by the prime objective of the first manned missions, which was medical and biological: can man survive and work effectively in weightlessness? All else seemed of secondary importance, and justifiably so. For medical and biological studies, launch time and other restrictions were irrelevant. The solar attitude control system, that was eventually adopted for the Vostok spacecraft, still had significant inherent flaws, as compared with the classical system that subsequently superseded it. The solar attitude control system could not, of course, function in the Earth's shadow, nor in particularly unfavorable positions of the Sun in relation to the spacecraft's orbit. At the same time, we had to provide for the possibility of an unexpected emergency on board the spacecraft that would cause it to execute an emergency re-entry, as in the event, for instance, of a sudden depressurization of the capsule. We decided, therefore, to add a manual spacecraft control system for the cosmonaut that would duplicate the automatic solar control system. The introduction of a manual control system should not be seen as adding to the complexity of the spacecraft's control system caused by the solar attitude control system, as the manual system was to be used, anyway, irrespective of the type of the automatic on-board control system. The addition of the manual control system was seen as a clear gain in the efforts to enhance reliability by system duplication. This was achieved not by means of installing more sets of identical equipment, but rather by using different types of control systems incorporating different principles (a combination of an automatic and manual control system, rather than two or three identical automatic ones). This type of duplication was unquestionably more reliable and efficient. In the end, the Vostok spacecraft carried three sets of automatic solar flight control systems working in conjunction and a manual control system. All of this made us confident of the success of the first manned space flight.

The desire to maximize reliability through design simplicity is clearly in evidence, as well, in the choice of the type of tiny reaction control engines used to position the spacecraft in attitude. It was clear that, to minimize the weight of the instruments and fuel for attitude control, we had to use tiny reaction control engines burning special rocket fuel. Now, work on such engines was well underway but their reliability seemed inadequate. Not to waste time, and to develop a trouble-free system, we decided to use compressed nitrogen rather than fuel, while replacing tiny reaction control engines with nozzles for nitrogen discharge. The resultant, somewhat heavier, attitude-control system for Vostok was balanced by its maximum simplicity and reliability.

The only thing that we failed to duplicate on that occasion was Vostok's retro-rocket. Its duplication would have increased the weight of the spacecraft well beyond what its launch vehicle could handle at the time. There was nothing for it but to choose a suitable orbit for the flight. The capsule carried enough water, food and oxygen for the life-support system to last ten days in orbit. We decided to proceed with caution, and we limited the first manned space flight to just one orbit. Vostok's Earth orbit had to be sufficiently low so that, in the event of failure of its retro-rocket, the spacecraft would decelerate and return back to Earth within less than ten days. In this scenario, however, it was impossible to predict the exact touch-down point, and we had to put our trust in international solidarity for the cosmonaut's recovery and rescue. Fortunately, this scenario did not materialize.

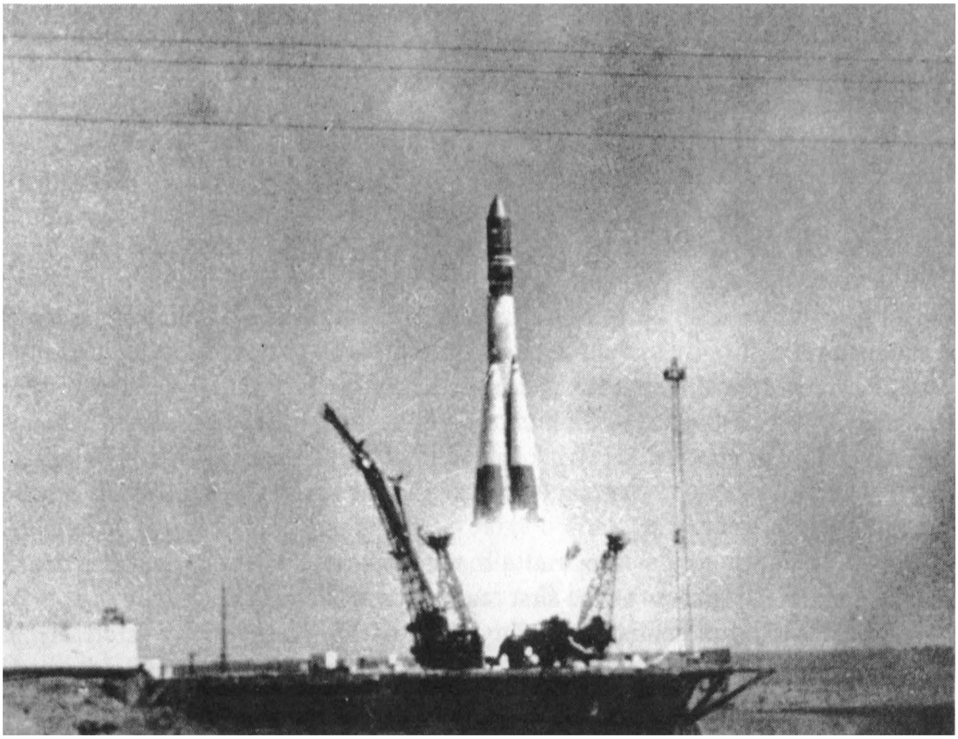

Figure 2 Vostok-1 spacecraft.

Conclusion

The desire to ensure the safety of the first manned spaceflight, in a situation where no previous experience of piloted space missions was available, resulted in the adoption of approaches noted for maximum simplicity, sometimes bordering on paradoxical engineering solutions.

Design simplicity, apart from increasing the reliability of all systems, also helped to reduce sharply the lead-time for the development of the Vostok spacecraft. This was an important gain in a situation marked by the "competitive rivalry" caused by the unofficial space race between the Soviet and American space programs.