History of Rocketry and Astronautics

Proceedings of the Eighteenth and Nineteenth History Symposia of the International Academy of Astronautics

Lausanne, Switzerland, 1984

Stockholm, Sweden, 1985

Tom D. Crouch and Alex M. Spencer, Volume Editors

R. Cargill Hall, Series Editor

AAS History Series, Volume 14

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 8

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 1993

ISSN 0730-3564

ISBN 0-87703-374-9 (Hard Cover)
ISBN 0-87703-375-7 (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.

AAS 92-314

Chapter 14

ENGINES AND PROPULSION UNITS FOR SPACE VEHICLES CONSTRUCTED BY ALEXEY M. ISAEV*

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This paper cannot describe the full extent of Alexey Michailovitch Isaev's works. The paper is an attempt to give a chronological account of Isaev's and his colleagues creation of liquid propellant engines and power plants for dynamically active space vehicles.

At the end of the 1950s the first artificial Earth satellite was created under the leadership of S. P. Korolev. Following this success, heavy Sputniks were successfully put into orbit, including the first manned Sputnik. It became necessary to create a piloted vehicle and automatic space vehicles for development and exploration of space. The dynamic characteristics of space vehicles demanded corresponding liquid propellant rocket engines and power plants.

To give life to this great and important project, Korolev offered the job to Isaev. His choice was not casual. Isaev, one of the pioneers of the rocket engine industry in the Soviet Union, was already experienced in the creation of liquid propellant rocket engines for various purposes, including those for aircraft and aircraft boosters.

The first work of Isaev's bureau was the creation of a retrorocket engine for the Vostok spaceship. Isaev's bureau created not only the engine for this project, but all rocket power plants. This bureau was responsible for weight reduction, reliability, and simplifying construction of the engine, as well as organizing and dividing the work between the various bureaus participating in the Vostok project.

The liquid propellant rocket engines for space deployment created by Isaev's construction bureau were autonomous propulsion systems. By the end of the 1960s, it became possible to put into near orbit heavier vehicles, or to give them second space speed. The bureau created not only engines for a number of systems, but

* Presented at the Nineteenth History Symposium of the International Academy of Astronautics, Stockholm, Sweden, 1985.

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developed the power plants used by the construction bureaus working on the spacecraft.

The Vostok's liquid propellant rocket engine provided a thrust pulse, and switched her from an artificial Earth satellite orbit into the trajectory of motion towards the Earth's surface. The liquid propellant rocket engines were of an open scheme, with a pump propellant supply system to provide one ignition of the engine, and they worked on high-boiling, self-inflammable propellant components. During operation, the retrorocket engine needed to stabilize the spacecraft because of the gas outflow from the nozzles. The control throttles distributed the gas expenditure between the nozzles.

When the first power plant was being built for a spaceship, a number of serious technological problems occurred which included: the starting of an engine in high vacuum conditions; starting and operation of an engine in a weightless environment; measuring the influence of high vacuum on different materials used in the engines; and the special requirements for hermetic preservation of liquid and gas chambers within the engines.

Isaev's inborn energy, initiative and ability to get to the essence of any problem, soon built a power plant. It took approximately seven months from the receipt of the technological assignment to the time the first retrorocket engine models came to the test grounds. The problem of ignition of compounds in the power plant chamber for the Vostok spaceship had a simple solution. An ejecting plug covered the chamber nozzle, and the chamber's void was supercharged with gas before launching (and before the supply of components). A number of power plants developed later used this system for ignition in a vacuum. Experimental work on deploying more energetically active pairs of propellant components demonstrated that ignition inside the chamber was normal even without initial pressure. This is why further developments in supercharging of chambers or the nozzle plug mounting were not utilized.

The mounting of the plug on the chamber nozzle was practically useless in engines and power plants of multiple ignition. In the absence of gravity, the different positions of the gas "cushion" of the propellant tanks could lead to engine ignition failure. It was necessary when the engine was ignited to avoid a gas "bubble" at the engine intake for the first five to eight seconds of operation. At the expense of the operating engine, separation of gases appeared, and normal levels of liquid surface in the propellant tanks was restored. Isaev considered many variants. He made the decision to put the volume of the propellant tanks (the "cushion") within an elastic compensator. The expansion of this container-compensator provided for engine operation for some seconds. Later, after ignition, the supercharging of the tanks was made straight into the tank, bypassing the compensator. In the introduction of that decision, film polymer materials, different for the oxidizer and for the propellant, were chosen for the container-compensators.

At that time Soviet industry lacked the capability to produce film material that was stable enough to contain the aggressive propellant components. There were only experimental laboratory makers of such film. This fact did not stop Isaev, who saw the perspective of future work in building rocket power plants of multiple ignition, provided with full expulsion of propellant by elastic separators. He attained the production of such films, which required substantial effort on the part of a number of cooperating ministries. Isaev's solving of this problem demonstrated his initiative and persistence. He displayed an ability to solve complex questions concerning construction, technology and organization to create new prototypes. These separators ensured full expulsion of the propellant. These retrorocket engines developed by Isaev were used in a number of space projects, such as the Vostok and Voskhod series.

Isaev also understood that the retrorocket engine for the Vostok was only the first step in a series of space rocket engines and power plants. As their characteristics improved and their purpose became more complicated, Isaev began to organize specialized laboratories and subdivisions to carry out research on scientific projects. This improved cooperation between various institutes, organizations, ministries and the U.S.S.R. Academy of Sciences.

During development and construction of the retrorocket engine, Isaev's bureau gained experience in space engine construction on which later works were based. The progress of cosmonautics and solution of problems connected with the exploration of near space (the Moon, Venus and Mars) required a multiple ignition liquid propellant rocket engine with long flight life. To solve this problem, Isaev's bureau built the first space liquid propellant rocket engine. The multiple ignition rocket produced a number of new problems to solve: providing a multiple supply of propellant components into the engine under the conditions of weightlessness; providing multiple ignition systems for the engines with different propellant supplies; building high revving turbopump assemblies; the need for high service life with means of their multiple spin up; combustion chambers of multiple ignition; quick acting pneumatic and electric valves that provided multiple operation, and that were leak proof and serviceable under the influence of high vacuum, radiation, and resistant to the corrosiveness of the propellant components; and developing methods and means for ground testing in conditions that simulated a space environment which could provide the maximum amount of precise data.

The first step in the manufacture of a multiple ignition liquid propellant rocket engine, was to work out a number of power plants that could provide a limited number of ignitions (two or three). These were for flights of long duration lasting from a few days to four or five months. The power plant with the turbopump supply system provided two ignitions. The first ignition made a small thrust pulse for vehicle trajectory correction; the second firing, which took the greater part of the propellant, was to reduce speed on lunar landing or for the transition of the vehicle into a lunar satellite orbit. That power plant saw new solutions based on a screened capillary grid device. This provided the supply of components in weightless conditions without the gas "bubbles." The *Luna-4* and *Luna-14* vehicles, the automatic lunar station and an artificial lunar satellite used this system.

This family of engines included several other power plants for space vehicles used in the exploration of Venus, Mars, and deep space. Besides furnishing a limited number (two or three) of ignitions, this series employed the expulsion supply system and the separators made of elastic polymer materials. Small thrust and low pressure combustion chambers with relatively high specific parameters were developed for these power plants. During engine operation, the power plant created not only a pulse thrust but also control movements to stabilize the vehicle along its pitch and yaw rotations. This was at the expense of the chamber swinging in a gimbal mount with the help of electronic servos.

The following automatic vehicles used these power plants: *Mars 1*, the first vehicle sent towards the planet Mars, which provided information on Mars' atmosphere; *Venera 1* through *8*, these vehicles provided the Soviet Union with the first Venus landing automatic stations and the exploration of the Venusian atmosphere; and *Zond 1* through *3*, these vehicles obtained information on deep space exploration and took photographs of the far side of the Moon for the second time.

In the mid-1960s, the progress of cosmonautics required new spacecraft power plants and engines which would provide long service life. They had to be capable of providing ignitions of hundreds of seconds, made dozens of times, and they had to have a supply tank with a capacity of hundreds of kilograms.

Safety always concerned Isaev when developing designs. But the construction of space liquid propellant rocket engines of multiple ignition and long service life made the problems associated with safety more acute. In that connection, methods and means of functional duplication were worked out. The elements of such duplication were already used with the retrorocket engines of the Vostok ships and the Vernier retrorocket on the Luna vehicles. Within the multiple-burn liquid propellant rocket engines of the mid-1960s, there were already installed the duplications of the whole system (or even of one engine); for example the power plant used for Soyuz. It is necessary to point out that in the power plant of Soyuz, the standby system insured not only the main engine, but also the spaceship's stabilization system.

The stabilization of Soyuz along all of its axes, with the standby engine operating, was accomplished by a system that included the exhaust of the turbopump assembly gas nozzles and the gas timing throttles. In the liquid propellant rocket engines of this period, devices for the identification of system failures were installed. These devices provided either an automatic transfer into the standby element, or, if there was a threat of mission failure, engine shutdown. Later, the analysis of the information received on those devices made possible the second firing of the rocket engine. All of the engines were equipped with the necessary systems to obtain the required information to estimate the serviceability as a whole and of some of its systems.

Isaev paid special attention to the automatic engine control system that controlled the power plants and engines with a minimum number of commands from the spacecraft control system. In most cases, there were no more than two commands: launch or stop. All other operations (turbopump assembly spin up, transition to self supply, stage launch, etc.) were conducted by the liquid propellant rocket engine itself, without the interference of the object control system. This substantially increased the reliability, and it clearly differentiated failure in case of emergency situations.

The creation of the liquid propellant rocket engines with multiple ignition required the development of new sub-assembly units, fixtures, and adjustments. Units combining the functions of several units were created. Thus, Soyuz's power plant had a multiple ignition unit on the turbopump assembly combined with the stop valve of the engine inlet. By analogy, there was developed a multi-functional valve for the power plant of the *Mars 1* automatic interplanetary station. This system was required to be leak proof, resistant to vibration, and the power plant needed to have small overall dimensions (the result of which was a very "tight lay-out") which predetermined making "all-welded" structures for the engines and power plants. This required, in turn, the development of new designs of the units' adjustments and fixtures.

The new requirements of space power plants and the engines dictated new principles of manufacturing. Isaev's bureau established the criteria for ground testing that modeled space conditions. These criteria consisted of modeling only those conditions which determined the basic processes in engines and power plants. The methods of ground finishing were worked out with regard for the maximum number of influencing factors, the most probable combinations of servicing time and number of ignitions and pauses, with the necessary excesses of the normal volumes. Isaev's ideas were confirmed by his experience with liquid propellant space rocket engines.

During the mid-1960s, the following engines and power plants were built: the power plant of the *Molniya 1* communication satellite. It employed the expulsion type supply system of multiple ignition with the swinging combustion chamber for stabilization in pitch and yaw axes. The elastic separators provided full propellant expulsion used in the modified version within the Molniya communication satellites up to the present time. The engine of the *Polet 1*, was the first maneuvering satellite which employed multiple ignition of the expulsion supply system. The power plant was designed by the leading construction bureau. These engines were installed along the object's grid axes. This produced the thrust pulse along the axes and ensured the Sputnik's ability to maneuver along all axes.

The Rendezvous-Vernier power plant of the Soyuz spaceship utilized the turbopump supply system with two engines (the main engine and the standby) with elastic separators inside the chambers. The standby engine had a gas system of nozzles placed along the grid axes and the gas distribution throttles. The gas worked in the turbine and outflow from the throttles-created control movements for stabilizing the ship during engine operation. The multiple ignitions of the Rendezvous-Vernier power plant created thrust pulses for orbital correction, rendezvous of two space ships, or a breaking impulse to transfer a ship from orbit to re-entry.

With the help of the Rendezvous-Vernier power plant, the first rendezvous and docking of two automatic Sputniks, *Kosmos 186* and *Kosmos 188*, was accomplished, and the first experimental space station, *Soyuz 4* and *Soyuz 5*, was set up.

The Soyuz spaceships with the help of the Rendezvous-Vernier power plant completed the rendezvous with the long life orbital stations of the Salyut series. The Salyut and *Salyut 4* orbital stations used a modified Rendezvous-Vernier power plant. The Rendezvous-Vernier was also used aboard the Progress ships, which are intended for supplying the orbital station with cargo and propellants.

The Vernier power plant of the *Zond 4* through *8* vehicles worked off the turbopump supply system of the multiple ignition. The control nozzles system operated from the turbopump assembly exhaust gas for vehicle stabilization during engine operation. The multiple ignitions from the Vernier power plant gave pulses for the translunar trajectory correction; the transfer of the vehicle into the circumlunar flyby trajectory correction; and the transfer of the vehicle into the Earth return path. The Zond series spacecraft were the first automatic vehicles in history that circled the Moon and returned back to the Earth.

In the late 1960s, with the construction of a more powerful launch vehicle, it became possible to increase the weight of the launched automatic space vehicles (in comparison with the payloads placed in orbit by the Vostok launch vehicles) for flights towards the Moon, Mars and Venus. K. N. Babkin's construction bureau carried on the work on these vehicles. For these heavy space vehicles a number of engines were created, some of which had several modifications, including the engine of the ascent stage of the lunar rocket. They secured the ascent of the rocket from the Moon for lunar soil delivery back to Earth.

All of the engines in this series had a turbopump supply system which provided not only the thrust pulse but also stabilized the vehicle during engine operation. The force and movements for vehicle stabilization were done at either the expense of swinging the combustion chamber in the gimbal mount, or at the expense of afflux of gas. The gas spent in the turbine from the nozzles was redistributed between the throttle-control nozzles. In some of the engines of that series, a new method multi-starting of the turbopump assembly was designed and employed. The supply of the propellant to the gas generator during ignition was accomplished by pressure in the main propellant tanks. The turbine inlet nozzles assisted acceleration of the turbine rotor spin up. The passage area of the inlet nozzles was considerably greater than that of the passage cross section of the variable nozzles. The in-take nozzles were started with the help of the gas valve on the entrance of the engine in the operating mode.

To increase reliability and prevent hidden flaws, Isaev proposed, designed and introduced to all of the engines of that series a new method of checking quality control by test firing every engine. The new test method did not require an engine overhaul after the firing tests. This was accomplished by clearing the engine voids of the remaining components after the firing tests. It required substantial design development, such as the exclusion of blind voids in the hydraulic passages, developing special technology to clear the passages and methods of its control. Experience demonstrated that the new method of clearing the engine voids of remaining components gave a satisfactory clearance of an engine which allowed further operation of the engine assembly.

The engines designed by Isaev's bureau for G. N. Babkin's heavy space automatic vehicles ensured the following: the first soft lunar landing and lunar take-off, which brought back lunar soil (*Luna 16*); the first soft lunar landing of the automatic station with the Lunokhod (*Luna 17*); the creation of the Venus satellite (*Venera 9* and *Venera 10*) and the first Venus landing of an automatic station which transmitted a television image; the construction of a Mars satellite (*Mars 2* and *Mars 7*) and a Mars landing of an automatic station to examine the Martian atmosphere.

In conclusion, it is possible to agree that the construction bureau under Isaev's leadership quickly created the designs of the engines and power plants for space vehicles, which represented an independent and new direction in space engine building for dynamically active space vehicles. The greater number of Soviet space vehicles in outer space were equipped with engines and power plants created by Alexey Michailovitch Isaev and the construction bureau led by him.