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Chapter 7

Leading Russian Liquid Rocket Engines' Company: To 75th Anniversary of NPO Energomash*

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Practically all space objects of the Soviet Union and Russia were put into orbit by liquid propellant rocket engines (LPREs) of NPO Energomash development, beginning with the first artificial Earth satellite, the first manned spaceship to the orbital stations, and the space orbiter Buran. And today the Russian human spaceflight program is conducted with help of the Soyuz launch vehicle, in which design improved versions of NPO Energomash engines are operating reliably. Performance of engines for Proton and Zenit launch vehicles are also improved permanently. And, since 2000, NPO Energomash engines are operating successfully in composition of U.S. Atlas III and Atlas V launch vehicles.

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NPO Energomash—a leading company in developing powerful liquid propellant rocket engines—is handling the full cycle of LPRE development, which consists of design bureau, manufacturing plant, and test facility (Figures 7–2, 7–3 and 7–4).

Figure 7–1: Academician Valentin P. Glushko, founder and long-term chief designer of NPO Energomash.

Figure 7–2: Location of main company in Khimsky and its branches.

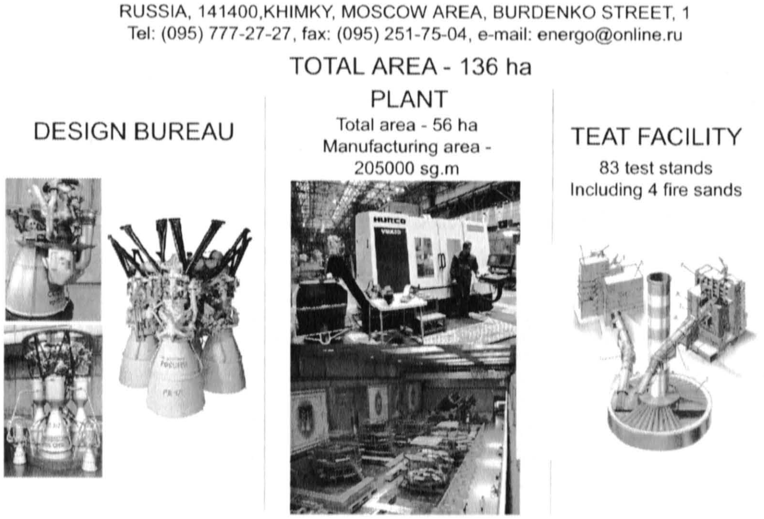

Figure 7–3: NPO Energomash named after Academician V. P. Glushko organization.

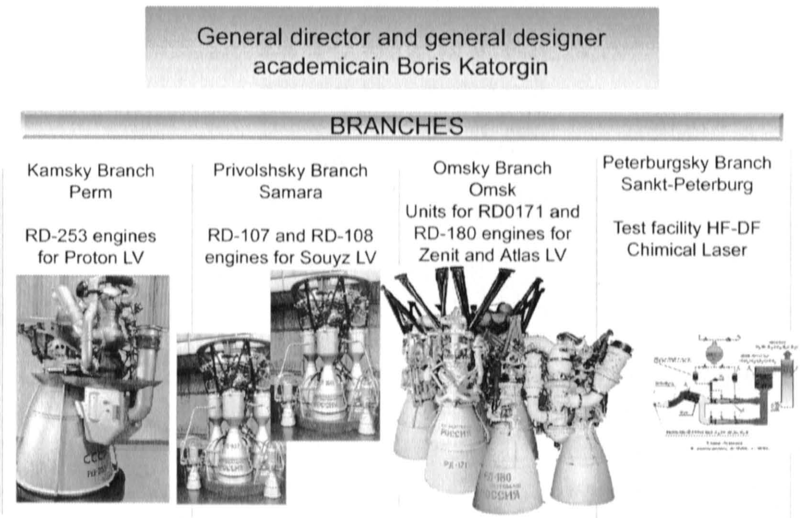

Figure 7–4: NPO Energomash branches.

Konstantin E. Tsiolkovsky's work *Study of the World Space by Reactive Devices* was issued in 1903. It put in play the fundamental theory of rocket engineering and astronautics. First, single scientists, and then organizations implementing the ideas for the creations of rocket engineering have appeared all over the world. These were Nikolay I. Tikhomirov's Laboratory, formed in 1921 in Moscow, and the activity of Robert H. Goddard, the American who executed the world's first flight of a liquid-propellant rocket in 1926, and activities of the German experts—Johannes Winkler and Hermann Oberth.

In May 1929, in Leningrad, a division under Valentin P. Glushko's management was organized in the structure of the Gasdynamic Laboratory (Figure 7–1). This division was engaged in the development of rockets and rocket engines. The first in the world electrical rocket engine and the first domestic LPRE—ORM-1 (Figure 7–5), which opened the line of experimental rocket engines (ORMs), were created and tested here at the beginning of the 1930s.

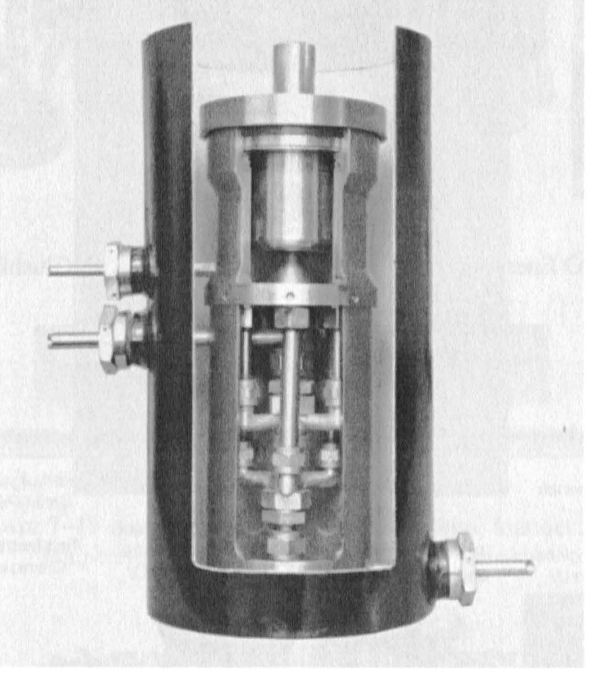

Figure 7–5: ORM-1, one of the first Soviet liquid rocket engines (1931).

The first domestic LPRE ORM-1 was developed in 1930–1931. It had a thrust of up to 0.2 kilonewtons (kN) (20 kilogram force or kgf) and a pressure in the combustion chamber of several atmospheres. It was intended for short operation with liquid propellant: nitrogen tetroxide with toluene or liquid oxygen with gasoline. At the beginning of his work Glushko conducted scientific research investigations, in result of which main design elements of future LPREs were fixed, and thermodynamics and heat transfer in the LPRE chamber was studied. In the 1930s more than 70 LPREs identified as ORM were developed. New technical innovation decisions were used in such designs. These were chemical and pyrotechnical ignition of the propellant, centrifugal injector elements, the reactive nozzle with spirally ribbed wall, being cooled by propellant, that is, film cooling of the combustion chamber. Design drawings of the turbo pump unit, consisting of a gas turbine with power of up to 35 horsepower (hp) and centrifugal pumps, were issued in 1932–1933, but turbine power unit (TPU) manufacturing was canceled at the stage of hydro testing of pumps, which created 75 atmospheres (atm) of head pressure at 25,000 revolutions per minute (rpm).

The first domestic LPRE to be applicable for a human flight was the ORM-65 developed in 1936 for RP-318 rocket glider and the 212 winged rocket (both designed by Sergei P. Korolev). One of the ORM-65 engines underwent 50 tests with about 30 minutes total duration.

In the 1930s and 1940s this collective, under the management of V. Glushko, changed places of location and also organizations, in which structure it worked, but the fundamentals of their activity remained invariable—liquid rocket engines.

During World War II the designs of aircraft LPRE-boosters for combat aviation were created: RD-1, RD-1KhZ with a thrust of 0.3 kN (300 kgf), RD-2 with a thrust of 0.6 kN (600 kgf), and the experimental three-chamber engine RD-3 with a thrust of 0.9 kN (900 kgf) (Figure 7–6). The developments of the engine RD-4 with a thrust of 2.0 kN (2,000 kgf) and an engine with a thrust of 3.0 kN (3,000 kgf) were also started. All these engines used nitrogen acid and kerosene as propellant.

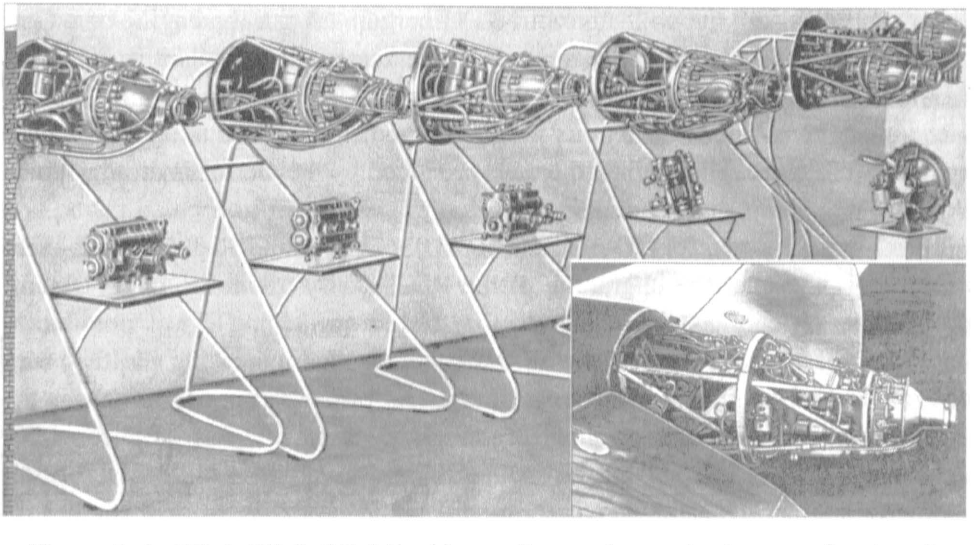

Figure 7–6: RD-1, RD-2, RD-3 liquid propellant rocket engine boosters for aircraft (1941 – 1945).

These engines took part in about 400 launches on airplanes of PE-2R of Petlyakov, LA-7R and 120R of Lavochkin, YAK-3 of Yakovlev, and SU-6 and

SU-7 of Sukhoi. The RD-1 and RD-1KhZ engines passed state official tests, the reports on which were approved by I. Stalin. In 1944 the RD-1 engine, and in 1945 the RD-1KhZ engine the serial production were launched. They were the first LPREs serially manufactured in our country. The problems of restart-ups of engines in flight both with electrical, and with hypergolic ignition, were solved. During these activities the wide experience of designing, realization of ground and flight tests of engines, and their subsystems was acquired, which served as the solid base to the subsequent developments.

In June 1945 a group of the experts from the Special Design Bureau of Reactive Engines was sent to Germany for learning the German superior engineering. Acquaintance with the German experience of developing the A-4 (V-2) missile and the comprehension of a necessity to have similar arms in the Soviet army promoted that in rather short terms the governmental order about a creation of the Special Committee on Reactive Engineering was accepted. Under this order a number of companies, including OKB-456 for powerful LPRE development, were organized.

Since 1946, the collective of experts under V. Glushko's management worked in Khimky, near Moscow. Powerful liquid rocket engines, the basis of the Soviet space program, and the basis of intercontinental ballistic missiles of the Soviet Union, were designed here.

In 1947–1948 the collective of NPO Energomash ran the engine of a German missile A-4 manufactured from domestic materials at a plant in Khimky. RD-100, developed for R-1 missile, was a copy of the German engine. The Soviet experts considered this activity as an achievement, because the manufactured engines were more reliable than the ones produced by the Germans during World War II.

The more powerful RD-101 and RD-103 for R-2 and R-5M rockets were accordingly designed by upgrading of the RD-100. By a number of design improvements on cooling, thermal protection and strengthening it was possible to increase pressure and temperature in the chamber thus increasing the fuel concentration. Many improvements were brought in, of which the main one was the design of a zone of internal cooling by a tangential swirl of a film of injected liquid. Many systems and parts of the engines underwent changes.

An attempt to develop more powerful liquid propellant rocket engines on the basis of a German design was undertaken. However, already the first fire tests of a LOX-kerosene RD-110 engine, with a thrust of more than 100 tons, showed presence of a great number of the complex problems involved in the given design of the spherical chamber, which sizes were changed by simple increase of scale. As researches have shown, the principle incorporated into the basic design of these engines, had limited prospects, because a way to further essential increase of thrust of the engine and especially of its specific impulse did not materialize.

The decision to terminate the development on the basis of the German engine design was accepted, and instead the work, which was conducted in parallel with the experimental chamber AD-140 (thrust up to 7 tons), was speeded up with the purpose to find an opportunity of increasing pressure and temperature of the gases in the combustion chamber. AD-140 tests in 1949 led to the conviction that the optimum form of the large thrust combustion chamber was the cylindrical one. Only such a form in combination with the flat injector head allowed for and ensured the maximum completeness of the combustion. Also the layout of the bipropellant injector elements was chosen, and its characteristics and scheme of locations were optimized. The much higher performance of the engine was achieved by application of the chamber design with brazed connections of a ribbed fire (inner) wall on tops of ribs with an outside load-carrying shirt. The design of cooling channels allowed using thin-walled heat resisting high-temperature bronze for manufacturing of an inner wall. The propellant component (usually fuel), cooling an internal wall, flowed in channels between ribs. The new chamber turned out to be durably efficient at temperatures up to 4,400°K of a high-pressure gas. This opened the opportunity of using a high effective propellant in the engines. Such design and technology for the manufacturing was widely begun to be applied in all subsequent developments of NPO Energomash and in other experimental–design bureaus of the Soviet Union.

The new designs of the combustion chamber were a genuine technical revolution in the field of LPRE development. They enabled the development of a chamber for practically any pressure within the limits of a technical feasibility and power balance of parameters of the overall engine. The combustion pressure of 24.5 atm in the RD-103 engine chamber of a R-5M missile was increased up to 260 atm in the chambers of RD-170, 171, 180, 191, and up to 300 atm in the chamber of the RD-0244 engine, designed in Chemical Automatics Design Bureau (CDBA) in Voronezh for a navy missile.

In 1957 the whole world learned about the successful flights in the Soviet Union of the first intercontinental rocket, which soon also put into orbit the first Earth satellites. In the first and second stages of the Vostok launch vehicle, with the help of which the first flight of man into space was carried out, four chamber LOX-kerosene RD-107 and RD-108 engines (Figure 7–7), with lateral steering chambers for the control of the rocket flight direction, were installed. A multi-chamber configuration allowed essentially reducing the length of the engine, which resulted in a reduction of the weight of the rocket. Besides, using such a configuration allowed for simplifying the development, with smaller size separate combustion chambers, including, a reduction of dimensions of equipment, necessary for the manufacture of these chambers. The principle of a multi-chamber configuration continued widely to be used in many new liquid propellant rocket engines of NPO Energomash.

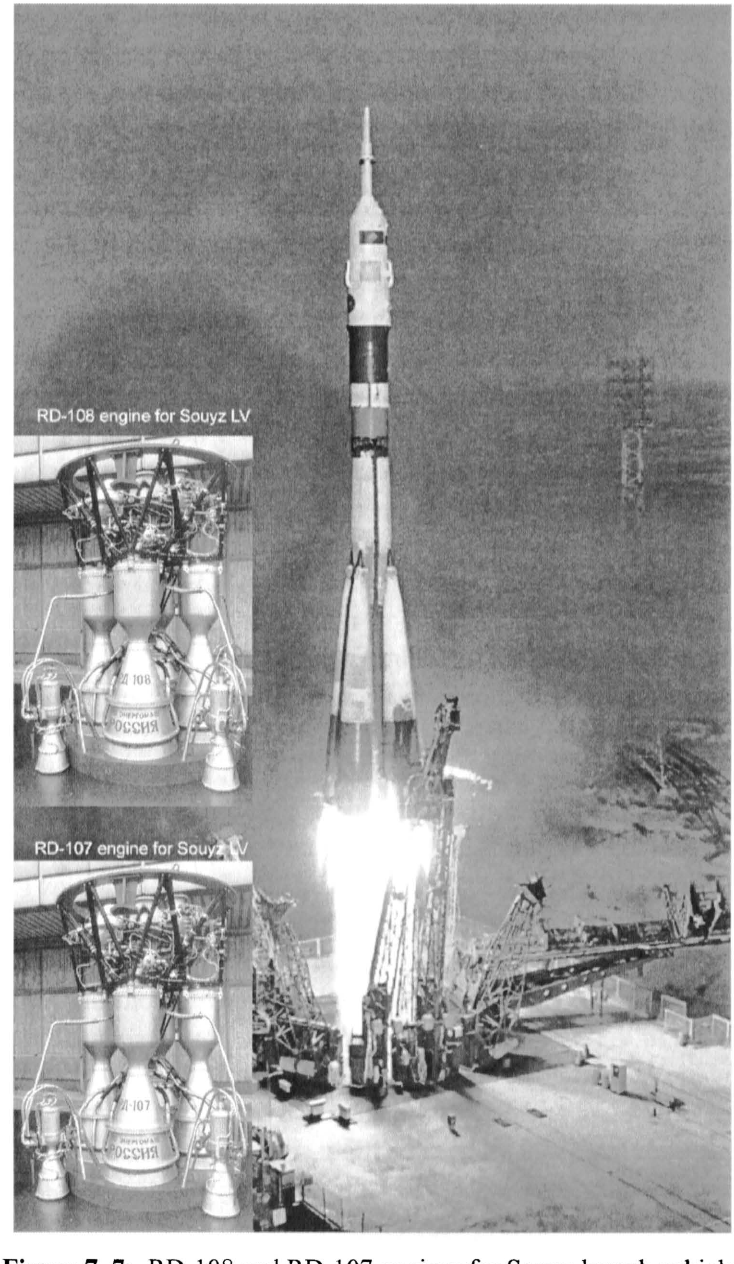

Figure 7–7: RD-108 and RD-107 engines for Soyuz launch vehicle.

In the special message to the Congress on 25 May 1961 the U.S President John F. Kennedy said that the Soviet Union had pioneered in space exploration because it had high-thrust rocket engines and precisely that factor put the Soviet Union in the lead.

The RD-107 and RD-108 engines were developed in 1954–1957. They and their modernized variants operated in space launch vehicles, which put into orbit artificial Earth and Moon satellites, and space vehicles for the research of the solar system. They reliably ensure the fulfillment of the current Russian program of human spaceflights.

In 1959–1962 during works on LOX-kerosene engines the RD-111 engine was developed. This engine, in contrast to RD-107 and RD-108, worked only with the main components of propellant without use of an additional third component for a TPU drive and didn't require special service during preparation for launch. Such engines were used in the first automated launch vehicle (readiness time—few minutes) and made it possible to launch this rocket either from a surface of Earth or from silos. For the first time the fuel-rich gas generator was used in this engine. Rocket flight control was conducted by gimballing of engine chambers.

It should be pointed out that all years in parallel with the development of engines for military missiles and space launch vehicles NPO Energomash conducted research for ways of further perfection of rocket engineering. In particular, our company is a pioneer in mastering new propellant components, such as UDMH, nitrogen tetroxide (N_2O_4), fluorine, ammonia, and hydrogen peroxide. Not all of them were permitted for service, but the research of a capability of their use was a powerful impulse of further advance of rocket engineering.

In parallel with these works NPO Energomash conducted development of engines for storable propellants for use in missiles. In 1952–1957 the nitrogen acid RD-214 liquid propellant rocket engine was developed. This engine started a line of powerful liquid propellant rocket engines using storable components of propellant.

The RD-216, RD-218, and RD-219 engines for the first and second stages of the R-16 missile, and as a variant thereof the Kosmos launch vehicle, were developed in 1958–1961. The six chambers RD-251 engine, consisting (and the RD-218) of three blocks of double chambers was developed in 1961–1965. As a result the problem of developing in a short time powerful multi-chamber propulsion systems using storable propellant components was realized by application of the block scheme of engines with the maximum commonality of elements. The engines of the last generation of this series promoted the maximum readiness of missiles at launch pad, which can be kept in a filled condition during many years.

The further increase of the specific impulse of the engines required an increase of the pressure in the combustion chamber that was limited by losses in a TPU drive. The final solution of this problem was found in the new scheme of the liquid propellant rocket engine, in which the turbine uses a preburner (or gas generator) gas, which was then afterburning in the main combustion chamber by mixture with a missing propellant component. By achieving a few hundred atmospheres of combustion chamber pressure this also allowed creating engines of large thrust with essentially reduced dimensions.

In the beginning of the 1960s, NPO Energomash turned to the practical mastering and implementation in powerful LPRE the scheme with generator gas afterburning. The RD-253 engine for the Proton launch vehicle (Figure 7–8) development in 1961–1965 was a major practical achievement. It is the most powerful single-chamber liquid propellant rocket engine, working with storable propellant components. For the first time in the world such a powerful engine was developed based on the principle with afterburning of an oxidizer-rich gas, which has significantly increased the performance of the engine. Six RD-253 liquid propellant rocket engines reliably operate in the first stage of the Proton launch vehicle, providing successful flights of Luna, Venera, Mars, and other space vehicles, and also the Salyut and Mir orbital space stations. Last year the 300th start of a Proton launch vehicle was carried out and the RD-253 engine is one of reliable LPRE in serial production. The modernized RD-275 engines with improved performances are used now in the first stage of the Proton LV.

In the following years further development of propulsion systems with a closed cycle of storable propellant components was conducted for missiles. The RD-264 and RD-268 engines were developed and are installed in modern high precision missiles. The pressure in combustion chamber of the RD-268 engine is equal to 230 atm.

Many design solutions used in these types of engines were designed for the first time for the RD-270 engine, which was planned to be used in the launch vehicle project UR-700, which was an alternative to the lunar N1 launch vehicle. This engine was designed for a thrust of 640 tons and a combustion chamber pressure of 266 atm. The engine should work under the "gas+gas" scheme and have two gas generators (preburners): one oxidizer-rich and one fuel-rich one. Propellant components were nitrogen tetroxide and UDMH. The work on the engine was canceled with the termination of all activities under the UR-700 project. The development of RD-270 LPRE, though it was not carried on to the end, yielded a powerful impulse to the development of methods and calculations of mathematical simulation of processes for start-up and shut-down. As a result today we have a perfect mathematical model of the LPRE, which is used widely already in the design phase.

Figure 7–8: RD-253 engine for Proton launch vehicle.

In 1985 the development was completed of the single-chamber RD-120 engine, intended for the second stage of Zenit launch vehicle, which was capable to put into low Earth orbit a payload of up to 12 tons.

Modifications of this engine, with truncated nozzle and gimbal mount or with steering chambers for thrust vector control, can be used in the first stages of a modernization of existing launch vehicles, for example the Soyuz LV, and also at the creation of new launch vehicles of small and medium classes.

The Zenit 3SL launch vehicle is the basis of the Sea Launch international program. RD-171 and RD-120 engines (Figure 7–9) of NPO Energomash development are used in the first and second stages of this LV.

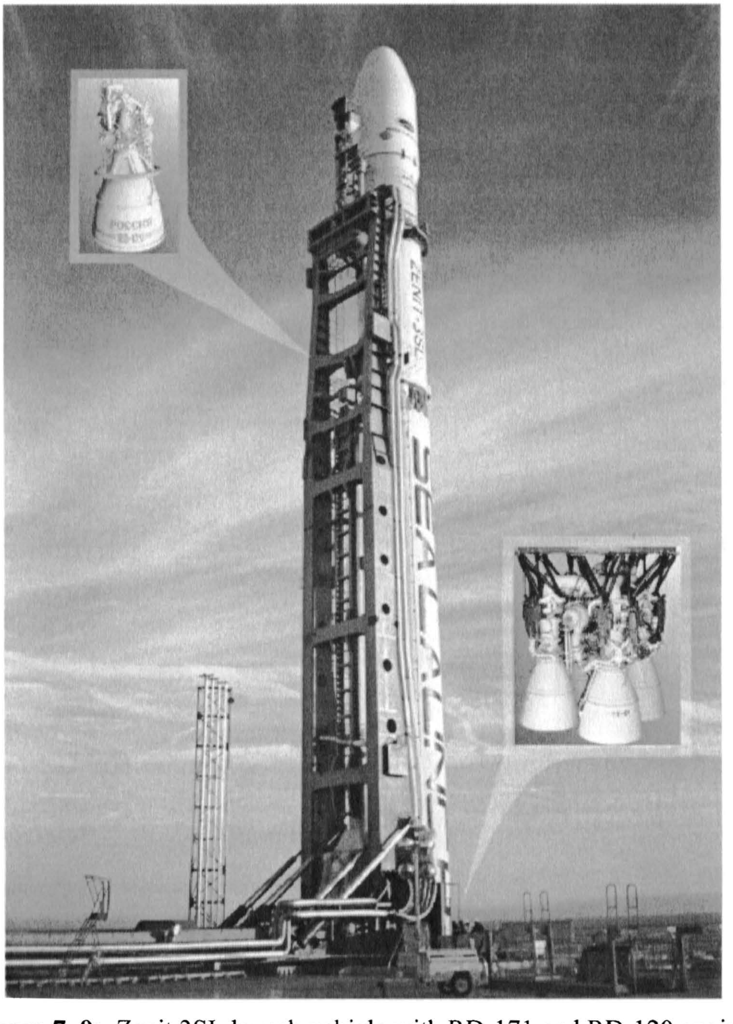

Figure 7–9: Zenit 3SL launch vehicle with RD-171 and RD-120 engines from NPO Energomash.

The development of the RD-170 engine and its modification—the RD-171 engine for the first stages of Energia-Buran rocket-space plane complex and the Zenit launch vehicle correspondingly—has become the significant achievement of NPO Energomash. The most powerful in the world RD-170 four chambers liquid propellant rocket engine has the best level of performance and characteristics for engines of this class. It operates on environmentally clean propellant components: LOX and kerosene. The engine is intended for reusable (up to 10 times) operation and one engine was tested for the start-up 20 times. The engine is characterized by high reliability of functioning during all operational phases, it can be repaired and controlled, and has large margin on life operation (not less than five). A special diagnostics system for post operation conditions of hardware was developed. The special technology of post operation processing of the engine for preparation of the engine for a new flight or test is mastered. The engine thrust vector control is carried out with the design of the chamber unique bellows gimbal joint, operated in a zone of high-temperature gas flow. The combination of its power and operational characteristics makes this engine superior throughout the world: it has neither domestic nor foreign analogues.

The engines, which are developed on the basis of the four chambers RD-170 liquid propellant rocket engine, have a plenty of attractive peculiarities and advantages, because they are based on well-proven designs of existing engine components and elements and require reduced time for development. The project of dual chambers, the RD-180 engine (Figure 7–10), was in January 1996 the winner of the competition on development and delivery of engines for the modernized Atlas IIAR launch vehicle of Lockheed Martin (United States). The activities on RD-180 development were conducted in cooperation with Pratt & Whitney (United States), with which in 1992 NPO Energomash concluded the joint marketing and licensing agreement of NPO Energomash engines in the United States, and in 1997 created a joint venture for marketing and manufacturing of RD-180. The fire tests of the RD-180 engine began in November 1996. The first serial production engine was delivered in the United States in January 1999. The first flight of the U.S. Atlas IIIA launch vehicle with a Russian RD-180 engine took place 24 May 2000. The first flight of the Atlas V launch vehicle also with use of the RD-180 engine in the first stage was carried out in August 2002. Eight flights of Atlas III and Atlas V launch vehicles have been conducted, 21 engines were delivered in the United States.

The development of RD-191 single-chamber engine (Figure 7–11) for the new Russian Angara launch vehicle family is being conducted at NPO Energomash. This engine is also based on the RD-170 engine design. The improvement of such engine for reusable operation in the structure of the Baikal stage is planned for the future.

During development of RD-170, RD-171, RD-120 engines, and later the RD-180 and RD-191 engines, a number of design and technological solutions (know-how) was realized. The majority of such decisions is protected by Russian and foreign patents.

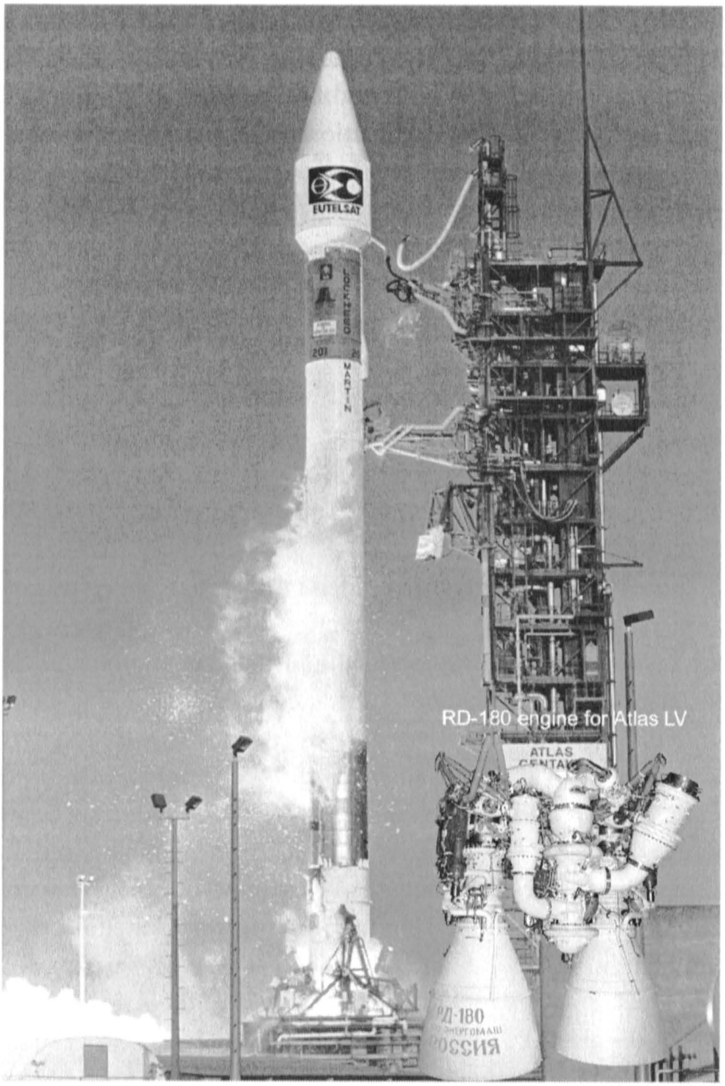

Figure 7–10: RD-180 engine for Atlas launch vehicle.

Special interest among the experts of a space industry of the whole world is directed to the projects of a tri-propellant two mode liquid propellant rocket engine of the RD-700 family. Such engines provide a consecutive work in first mode by three components (oxygen–kerosene–hydrogen) with the maximum thrust, and then at second mode by two components (oxygen–hydrogen) with the maximum specific impulse. It is designed for reusable (up to 15 times) operation of the engine. The dual chamber RD-701 engine was intended for reusable aerospace systems (MAKS), and the single-chamber RD-704 engine can be used as the basis for the design of the envisaged concept of a single stage to orbit launch vehicle with vertical launch and landing.

Figure 7–11: RD-191 engine for the new Russian family of Angara and Baikal launch vehicles.

NPO Energomash conducted tests of an experimental tri-propellant LRPE, injector head of which has 19 injector elements, developed for RD-704 engine main combustion chamber. For the first time in rocket engine history an opportunity of combustion of three components in one combustion chamber with achievement of a high efficiency of burning, that proves a basic opportunity of creation of a new generation of liquid propellant rocket engines, was confirmed by experimental research.

Since 1982, the initial research of engines for the use of liquefied natural gas (methane) as prospective fuel in a combination with liquid oxygen as an oxidizer are being conducted in NPO Energomash. Some such engine projects are under development now and design estimations for the transformation of such an engine as RD-120 from kerosene to methane for heavier launch vehicles are being carried out. NPO Energomash participates now in the joint Russian–European activities on the Volga program with the purpose to define the possibilities of the realization of a new generation of reusable LOX-methane engines.

The important area of NPO Energomash activity is the modernization of the liquid rocket engines, operated in various domestic space launch vehicles, with the purpose of improvement of their characteristics (increase of specific impulse, thrust of the engine, and as a result—increase of weight of payload).

First of all it is related to activities on engines for the first and second stages of the Soyuz launch vehicle. These engines with a new injector head were designed at the end of the 20th century, and the first launch of the Soyuz-FG launch vehicle with the upgraded engines was carried out in May 2001. The new design of the engine has allowed increasing by 300 kilograms the weight of the payload due to an increase of the specific impulse by 4.5 seconds. The work on use of these engines in a Soyuz launch vehicle with a system of hypergolic ignition instead of pyrotechnic is now being conducted.

One of safest space launch vehicles in the world, the Proton LV has been used since 1995 in a configuration with a first stage including the upgraded RD-275 engines, which thrust is increased by 7.7 percent, which in turn has increased by 600 kilograms the weight of the payload. The activities on modernization of engines of the first stage for the Proton launch vehicle are prolonged: the improvement of the new RD-276 engine (thrust increased by 5.3 percent) is being completed, and will allow increasing the weight of the payload even more.

Although the Zenit launch vehicle has been in operation only since 1985, NPO Energomash upgraded its engines also. The RD-120 engine for the second stage has a thrust of up to 93 tons instead of 85 tons and successfully has conducted the first flight in the configuration of the Zenit 3SL launch vehicle under the Sea Launch program in June 2003. And in March 2004 NPO Energomash delivered to Ukraine the first serial production upgraded RD-171M engine for the first stage of the Zenit 3SL launch vehicle, which will be used also in fulfillment of the Sea Launch program.

In summary one can give some numbers describing the achievements. The engines developed in NPO Energomash were installed into 21 military missiles and into 20 space launch vehicles in first and second stages, 54 engines have been in operation.

These engines have ensured about 1,700 flights of the R-7 (now Soyuz) launch vehicle and its modifications, 300 flights of the Proton launch vehicle, more than 500 flights of the Kosmos-2 and Interkosmos launch vehicles, about 1,000 flights of the Kosmos-3M launch vehicle, more than 250 flights of Cyclone-2 and Cyclone-3 launch vehicles, about 60 flights of Zenit and Zenit 3SL launch vehicles, 2 flights of the Energia launch vehicle, and 8 flights of the Atlas III and Atlas V launch vehicles.

In total, about 14,000 units of engines manufactured under the design responsibility of NPO Energomash have operated successfully in a complex of space launch vehicles flights since October 1957. To these numbers it is possible to add hundreds more engines successfully operated in experimental tests on a test stand and in a number of missiles during flight-design tests and training launches as well.

Today one can say with confidence, that NPO Energomash is one of the world leaders of rocket engine engineering.