NUCLEAR ROCKET ENGINE

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Abstract

This article describes a solution to the problem of insufficient capacity of existing rocket engines for interplanetary missions. Development in the sphere was analyzed by comparing the examples of the rockets of 1970 and present time. Further development of the nuclear engine is discussed.

Keywords:liquid rocket engine, nuclear rocket engine, nuclear lift, interplanetary flights, Z-pinch effect.

INTRODUCTION

Classic liquid rocket engines opened the way to space for mankind but now they are absolutely unpromising. They can be used only to launch a satellite or to fly to the Moon. These engines are useless for long flights: its exhaust velocity does not exceed 4.5 km/s, instead of the required dozens of kilometers per second. In addition, there is an impact of economic factors: according to the Tsiolkovsky equation, to reach the final velocity greater than the flow rate of the exhaust, the expendable mass should be significantly more than remaining. However, in the scale of interplanetary flights, the total cost of fuel is enormous.

The formula of thrust includes the average velocity of gas molecules emitted from the nozzle of the rocket engine. It can be increased in two ways: by increasing the temperature in the combustion chamber or lowering the molecular mass of the exhaust. However, the mass reduction does not lead to a substantial gain in speed because even if we are using the best oxidant (O_2) and fuel (H_2) the maximum increase in the velocity is only half of it, which is insufficient for long-range flights. So modern engine constructors are increasingly re-considering the first way – to heat exhaust up to a high temperature. Still, how to implement it? The answer to the question seems obvious now - nuclear energy. According to the calculations it turned out that it would be twice as efficient as oxygen–hydrogen fluid rocket engine (FRE). [1]

NUCLEAR ROCKET ENGINE

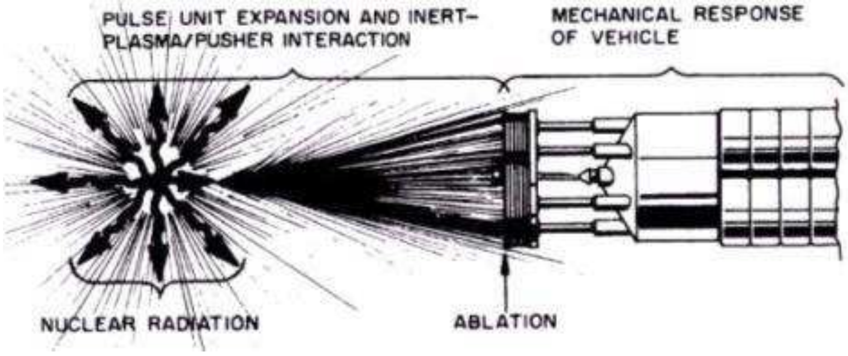
Nuclear rocket engine (NRE) is a kind of a rocket engine which uses the energy of nuclear fission or fusion to create jet thrust. NRE was developed in the USSR (RD-0410) and the USA (NERVA) in the mid-1950s. The research is continued at the moment. There are two types of NRE: pulse-explosive and liquid.

PULSE-EXPLOSIVE NRE

This type of engine was developed in the U.S. and the USSR during the 1950-70's. The most famous project of PENRE was the American ship "Orion". The spacecraft ejects a small nuclear charge that explodes within a short distance from the spaceship (up to 100 m) in the opposite direction of the flight. The charge is designed the way that most of the products of the explosion in the form of expanding plasma front is sent to the tail of the spacecraft where the massive reflecting plate accepts pulse and transmits it to the ship through the shock absorbers. Additional thrust is created by the ablation (evaporation) of the plate surface under the influence of gamma and X-rays. Reflecting plate is coated with graphite grease which protects it from the damage from gamma radiation and high-temperature plasma. When the height and the speed have been increased, the frequency of the explosions can be decreased. The ship is predesigned to fly vertically during the takeoff to minimize the area of radioactive contamination of atmosphere. According to calculations, nuclear pulse spaceship would reach Alpha Centauri in 130 years, reaching the speed of 10 000 km/s. However, further funding of the project was denied.

In the USSR, a similar project contained additional chemical thrusters that lifted it 30-40 km above the Earth, and then the basic nuclear pulse motor was activated.

The main problem of these projects was the strength of the screen-pusher which didn't stand against enormous heat loads from nearby nuclear explosions and radioactive waste pollution. None of these projects had been completed by the end of 1960. USSR and the USA stopped funding. The actual testing of pulse NRE with detonating a nuclear device was not conducted. [2]



Picture 1: structure of pulse-explosive NRE

NUCLEAR JET ENGINE

The principle of operation of NJE is a high temperature heat-exchanger into which a working fluid (liquid hydrogen) is introduced under high pressure and then heated to a high temperature (3000° C) and ejected through a cooling nozzle. Heat recovery in the nozzle is very beneficial as it allows to heat up hydrogen much faster and by utilizing a significant amount of heat, increase the specific impulse up to 1000 seconds (9100 - 9800 m/s). [3]

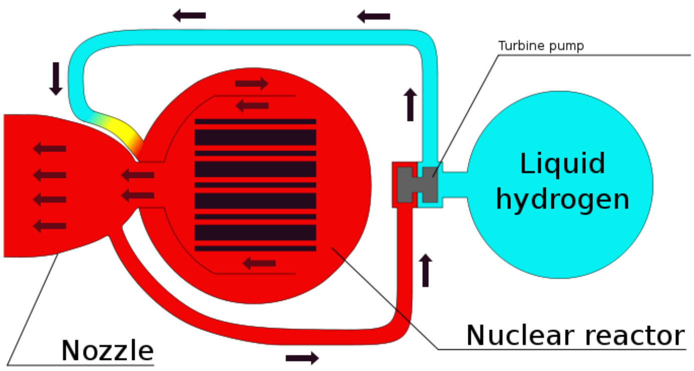


Figure 2: structure of nuclear jet engine

RANGE were positioned as engines of ships for travelling to Mars and were developed in the USSR (RD-0410) and the U.S. (NERVA). Despite the fact that both projects stood a full course of tests and proved to be successful, no NRE has been run for the lack of funding, which was caused by the prolonged space race. [4]

Table 1: The results obtained at the reactor IVG-1 and program development in the U.S. NRE

	USSR	USA	
Period of research activity	1961-1989	1959-1972	
Money spent, billion $	~ 0,3	~2,0	
Number of reactor units manufactured	5	20	
Fuel composition	solid solution UC-ZrC, UC-ZrC-NbC	UC2 in graphite matrix	
Calorific core, average / maximum, MW / l	15 / 33	2,3 / 5,1	
The maximum temperature, K	3100	2550	2200
Specific impulse, sec	~ 940	~ 850	
Resource at the maximum temperature of the working fluid, sec	4000	50	2400

NUCLEAR LIFT (RUSSIA)

NRE shows its best performance at high payload mass, so its most rational use is the implementation in the transport and energy module (TEM) which can provide a 30 times increase in energy level of a spacecraft and a ten times increase in the fuel efficiency of the propulsion system .

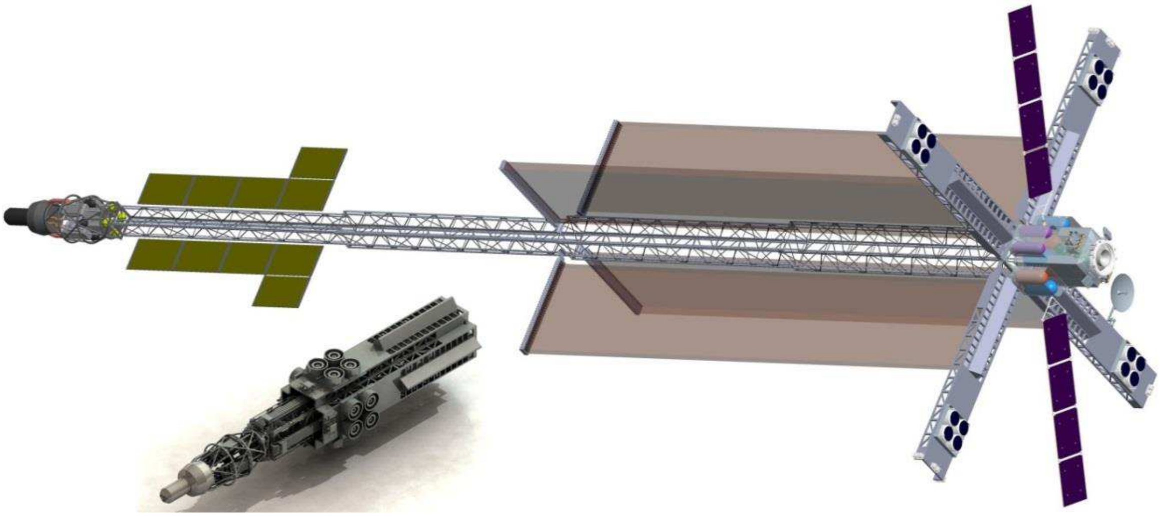


Figure 3: structure of nuclear lift

Taking into account the problems of NRE of previous generations, Russian scientists proposed the scheme of a hybrid engine in which the reactor did not heat the jet ejected from it, but produced electricity. Hot gas from the reactor spins the turbine; the turbine spins the generator and compressor that provides circulation of the working fluid in a closed loop. The generator produces electricity for the plasma thruster with a specific thrust which is

20 times greater than that of chemical analogs.

The main improvement is that exhaust from the new engine will not be radioactive, since a completely different working fluid contained in a closed circuit passes through the reactor. Also, in this scheme it is unnecessary to heat hydrogen up to extremely high temperature, as the inert working fluid circulating in the reactor is heated up to 1500 degrees. [5]

A ground prototype reactor plant is planned to be created by 2015, and by 2018 the reactor facility is to be constructed and its test is to be started in Sosnoviy Bor. The first flight test of TEM may be conducted in 2020. The major organization responsible for developing the nuclear reactor itself is the Scientific Research and Design Institute for Energy Technology (NIKIET), a member of Rosatom. [6]

Table 2: Specifications of nuclear lift [7]

Weight, kg	20290
Dimensions (position), m	53,4 × 21,6 × 21,6
Electric power unit, MW	1,0
Specific impulse electric propulsion, km / s	min 70,0
Power electric propulsion, MW	max 0,94
Overall thrust propulsion electric propulsion, H	min 18,0
Resource, years	10
Launch vehicle	RN "Angara-A5"

THE ENGINE ON THE Z-PINCH EFFECT (USA)

The pinch effect is the compression of plasma as the result of the interaction between the discharge current and the magnetic field. If the current flows along the axis of the cylindrical plasma column, it is called a Z- pinch. Z-pinch can be observed, for example, when lightning strikes a lightning rod in the tube. This effect is used to stabilize plasma in fusion reactors, and NASA has great expectations for it.

The economic aspect is always slowing the development of classic rocket engines: it is necessary to burn thousands of tons of fuel to transport only dozens of tons of payload. NASA sees a solution to this problem in the use of fusion engines as, besides their relatively low fuel consumption, they provide multiple capacity increase. The basic idea of this engine is following: in a parabolic combustion chamber the two components of fuel (deuterium and Li_6) are mixed; and a powerful electric pulse from capacitor turns them into plasma. The magnetic field of a large magnitude compresses the plasma and fusion reaction is ignited. The result is expanding plasma, which has a total weight of 0.02 kg, but its initial kinetic energy reaches 1 GJ. Then it is compressed by Z-pinch effect and ejected from the magnetic nozzle, creating reactive thrust.

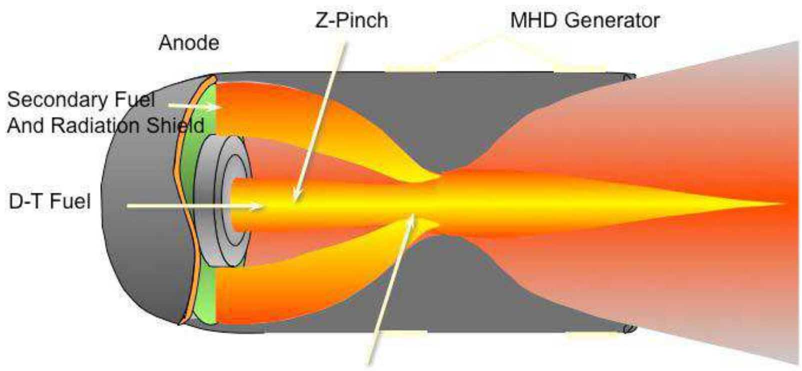


Figure 4: The engine on the Z-pinch effect

The main function of Z-pinch effect is to protect the engine from damage and to send a very large current through the dense plasma in a very short time (about 6.10 seconds).

The output is the reactive thrust of 3812 newton - seconds per pulse at the frequency of 10 pulses per second and the specific impulse of 19,436 seconds.

The engine is cooled with the liquid of fluorine - lithium- beryllium (FLiBe), which is also able to absorb gamma rays and neutrons. [8]

CONCLUSION

This article contains a review of the solution to the problem of inefficiency of liquid rocket engines for interplanetary missions. The use of atomic installations as engines for spacecraft was found as the most appropriate solution. The article gives a comparative analysis of the most interesting developments in this sphere under the authorship of scientists from the two major space powers - Russia and the United States. Two stages of formation of the NRE are considered. On the basis of the material studied it may be concluded that the interest in the NRE is increasing due to its perspective technologies in terms of capacity and efficiency. But it is necessary to mention the factors affecting adversely its development. First of all, it is the fear of radiation threat to the society: there are international rules prohibiting the use of the NRE at the altitudes less than 800 m above the surface of the Earth. Secondly, it is the fact that most NRE developments are only under conceptual design and scientists have to solve many problems before creating a real model of this engine.

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