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Space Guns for the Moon and on the Moon

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Abstract: Space gun—a device for launching objects in space. It refers to rocket-free methods of output objects into orbit. Space gun is not able to deliver the object in stationary orbit around the planet, for this, it must be equipped with a rocket engine to adjust the course after launch the object. This makes it possible to replace the existing excessively expensive rocket systems with new methods of delivering payload (space gun). Thus, the costs of scientific programs are decreasing at times, and many studies are becoming available, less risky and environmentally safer.

Key words: Moon, ballistic method, space gun, less risk, safety.

1. Introduction

Small planets and satellites, devoid of the atmosphere and their research—mainly determine the tasks of space expeditions of the near future. The moon is the most interesting and achievable object for study. It should be noted that studies of the structure of the Moon, although they brought important discoveries, are still far from completeness. In view of the limited volume of observations, the structure, composition, and state of the Moon matter at great depths are not well known and the interpretation of observations is ambiguous. There were also new structures for studying—for example, caves of supposedly volcanic origin. At the same time, within the old paradigm of lunar seismology, there already exists a fleet of methodological geophysical and geochemical studies. To implement the seismological method (a set of numerous design and technological solutions), a new paradigm of investigation with multiple penetrators deepened into the surface of the Moon is proposed. The main task, however, is to deliver the penetrators to the Moon with minimal costs. For carrying out seismological studies of the Moon, the level of development of modern scientific and technical systems and methods should be high enough [1].

Relying on this, space gun seems to be great candidate to maintain our task. Large overload experienced by an object in gun does not allow using it with delicate instruments into it, but to deliver the goods such a fuel or increased strength satellites and it is not a problem. In the following, we will discuss how such a space gun can be made and which parameters it should have, based on the past and current projects.

2. Completed Projects

Usual firing range of field artillery has limited distance from 15 to 300 km at a muzzle velocity of 1,500 m/s. However, there are many pilot projects with a new result, and the most important of them is discussed below.

The Range G facility has a long history of offering unique test capabilities through continuous capability improvements that provide the testing community a variety of test environments they require to obtain useful data. The Range G complex which has the largest operational two stage light gas gun with over 7,000 launches was performed in 47 years of continuous operation at the Arnold Engineering Development Center in Tennessee. The launcher

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employs 100 foot long 14 inch bore pump tube and explosively driven piston to compress hydrogen gas to extreme pressures and temperatures. The compressed hydrogen gas in turn drives projectiles to extremely high velocities through 130 to 192 foot long barrel assemblies with either 3.3 inch, 4.0 inch, or 8.0 inch bore diameter. Various combinations of barrels, pistons, and other launcher components allow a wide variety of test conditions to be accomplished with this launcher. Fig. 1 shows typical test conditions varying from launching 500 gram projectiles at 7 km/s with 80,000 G's maximum acceleration loads to 15 Kg projectiles launched at 3 km/s with 10,000 G's acceleration loads. Simple types of projectiles launched in Range G include rods, cones, spheres and other special shapes requiring a matching sabot with zero or non-zero induced flight angles. More complex types of projectiles include scramjet projectiles with multiple flow paths, cupped projectile sabots launching multiple piece projectiles or liquids, and projectiles with internal voids or combinations of materials used to simulate mass variations along an axis. Finally highly complex projectiles are fitted with internal components, pressure vessels, gas generators, in-flight material ejecta, nozzles, or other detail features. Using cupped sabot projectiles a variety of materials of all sizes and shapes can be launched into targets to simulate the effects of random low mass space junk. This technique could be used to impact common space materials such as mylar bits, paint chips, small fasteners, and a variety of other things of interest into materials or targets. On the other hand large scale high fidelity projectiles have recently been launched at low peak acceleration loads allowing simulation of complex flight vehicle impacts into realistic stationary targets at various engagement angles and pitch or yaw rates [2].

An American-Canadian Project HARP (high altitude research project)—project witch withdrawal of artificial earth satellites into low orbit with a special light-gas guns. The project began in 1961. At first, it was implemented within the framework of studying the behavior of ballistic objects in the upper atmosphere, and then they were interested in the military. It suggests the possibility of rapid withdrawal of satellites into low orbit and destruction enemy satellites. The culmination of the HARP project was the 16-inch (406-mm) gun mounted on the island of Barbados in the Caribbean. To improve the internal ballistics of the projectile before the shot, a technical vacuum was created inside a barrel. A length of barrel is reached 40 meters, the weight of the shells—180 kilograms at initial velocity—3,600 meters per second (3.6 km/sec—approximately 50%

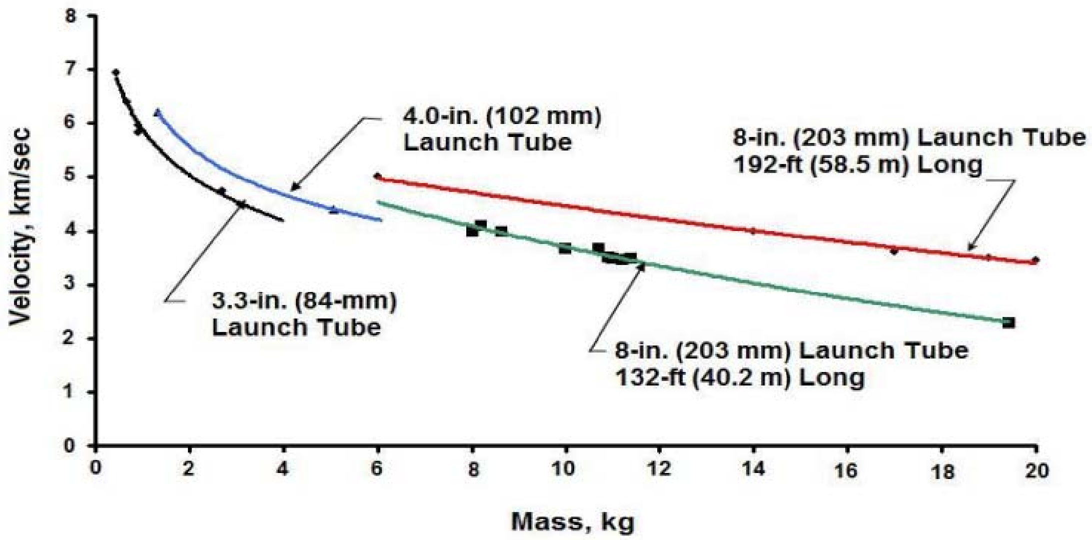

Fig. 1 Maximum velocity as a function of projectile mass and launch tube configuration.

of the orbital velocity). Cannon threw projectiles at a height of 180 kilometers.

However, it was not enough for the withdrawal of satellite into a permanent orbit. At the end of the HARP program, the shell-missile "Marlet" for taking out a satellite on the orbit was designed. In 1967, the project was canceled. At the end of the eighties this achievements were used in the Iraq project to create super gun called "Babylon". The UN carried out the final liquidation of the program after the Iran-Iraq war in 1991.

Project "Babylon" purpose was to create a series of the super guns. The design is based on the HARP project studies under the guidance of the Canadian artillery expert Gerald Bull. Despite the lack of information, it is known that there are four different devices, which have been included in this program. At least one of the projects of "Babylon" ("Great Babylon") using the modified principle of the "theoretical" artillery (V-3). The gun has had besides the usual propellant charge located in the breech, many charges of propellant, which are moved together with the projectile, and as it moves along the trunk, constant pressure is supported in it. Nine tons of special propellants provide a fire of 600 kg projectile to a distance of 1,000 km. Such a projectile could launch a 200-kilogram satellite into orbit at a price of \$600 per kilogram. The caliber of the gun is 1,000 mm. It is known about testing a prototype 350 mm caliber.

For comparison, modern missile provided price at \$6,000-10,000 per kilogram for the lowest reference orbit. Only Space X goes further with their new partially reusable missiles with price around \$1,500 per kilogram of useful load.

In another project, in Lawrence National Laboratory in Livermore John Hunter headed the largest project of the light-gas gun in the world—SHARP (Super High Altitude Research Project), which had successfully worked since 1992 to 1995.

At the first section (with a caliber of 36 cm and 82 m long) of this L-shaped installation, methane is burned, the products of its combustion push a steel piston that squeezed hydrogen located on the other side. When the pressure reach 4 thousand atmospheres, a special fuse is destroyed, hydrogen enter in the second trunk (10 cm by 47 m), and a 3-5 kg shell accelerating with speed around 3 kilometers per sec.

Later, this gun was planned to be modified for anti-aircraft fire (during testing it was in horizontal position) and to increase the speed of the shells to 7 km/s, which corresponds to space launches. But these plans were not implemented for financial reasons.

It should be noted that light-gas guns of much smaller size and with much smaller mass of shell make

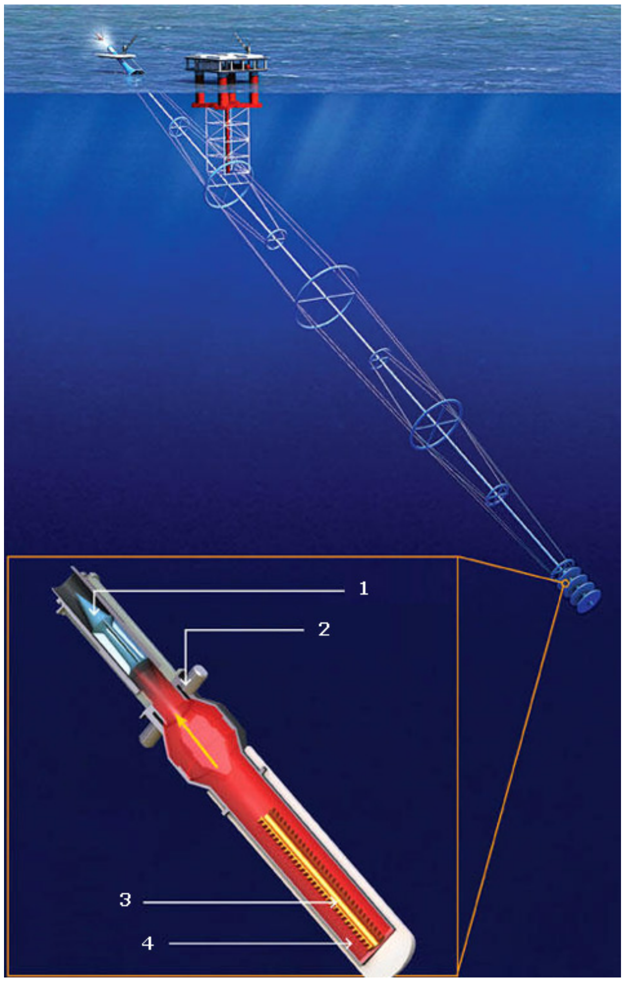

Fig. 2 Scheme of the new Hunter's gun: 1—shell, 2—valve, 3—combustion chamber, 4—Hydrogen (Illustration in Popular Science magazine).

velocity up to 11 km/s, but the mass output into orbit will be several grams.

These instruments, however, were created for other purposes: the study of the flow past bodies on hypersound, the behavior of materials at enormous pressures and temperatures (developed at the moment of impact of a velocity projectile into a target), and modeling of spacecraft erosion under the influence of micrometeorites. For the conversion of such guns into cosmic ones, a revision of their device is required.

3. Quicklaunch

The most successful project in this area was made by John Hunter, an American scientist and engineer, president and one of the founders of Quicklaunch, set itself the goal to organize the output of small vehicles in to space using a gun at 1.1 kilometers in length [3].

The main change in the new system is marine basing, which gives a lot of advantages. Such a technique solves the problem of curvature of the barrel under its own weight. It is easier to point the barrel along the azimuth if it is necessary to change the inclination of the orbit). Also, the gun can easily be towed to any desired place on the equator (optimal for launching spacecraft).

Since the two-stage LGG was invented by Crozier and Hume, many two-stage LGGs have been built all over the world. Many laboratories and research institutions, such as NASA (National Aeronautics and Space Administration) Ames (USA), NASA JSC (Johnson Space Center) (USA), AEDC (Arnold Engineering Development Center) (USA), EMI (Ernst-Mach Institute) (Germany), French-German Research ISL (Institute of Saint-Louis) (Germany and France), HAI at CARDC, etc., have their own two-stage LGGs. A typical two-stage light gas gun consists of powder chamber/air chamber, pump tube, high pressure section, and launch tube. As its name implies, the two-stage light gas gun has two stages. The first stage is the powder gun or air gun, with which a piston is accelerated in the pump tube, compressing the pre-filled light gas (e.g. hydrogen or helium). The second stage consists of the high pressure section and the launch tube. The compressed light gas (up to about 10 thousand bar) in the high pressure section accelerates the test model/projectile sabot combination. Roughly estimated, the maximum achievable muzzle velocity is the gas escape velocity, which is attained when the gas pressure drops to zero when a complete vacuum reached. The escape velocity is proportional to the initial gas sound speed, which is related to the molecular weight (hydrogen is lighter than helium) and temperature of the gas. The lighter the gas is, the higher is its escape velocity. Both hydrogen and helium could be used as the driving gas in the pump tube. While helium is much safer than hydrogen, the latter is considered more efficient taking into account of launch capability.

In Quicklaunch, Hunter got rid of the piston. In the new system, natural gas burns inside a special heat exchanger chamber, which is surrounded by a second chamber—with hydrogen. Heat is transferred through the walls, resulting in the temperature of hydrogen rising to 700 degrees Celsius. As soon as the pressure reaches the required value, a special sliding valve opens and hot hydrogen starts to accelerate the projectile along the trunk. After the departure of the device, the end of the barrel immediately closes the diaphragm, minimizing the loss of hydrogen—it is then cooled again to be used in the next launch.

According to the calculations of John and his associates, the Quicklaunch gun should throw 450 kilograms at a speed of six kilometers per second. And although the overload at the shot will reach 5,000 g, it is now quite possible to create satellites, the electronics and useful load of which will withstand such a start.

Prior to the first space speed, these devices should be overdrawn already at the top. At an altitude of 100 km, such a projectile dumps the fairings and turns on its own miniature rocket engine.

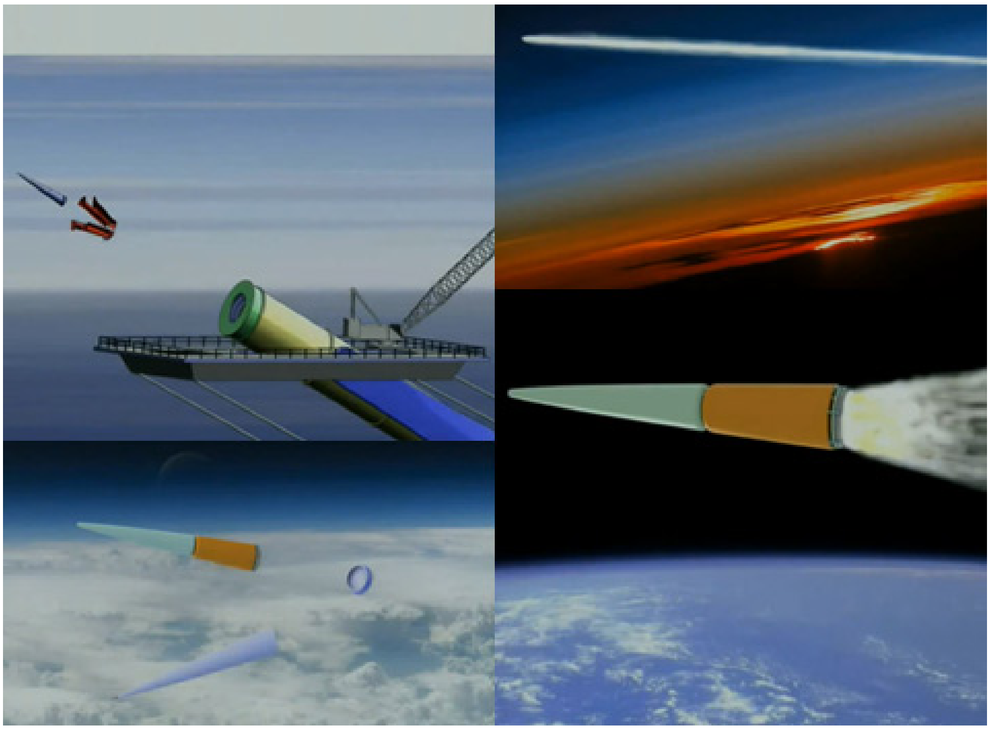

Fig. 3 Scheme of the flight of a sub-caliber space projectile fired from the Quicklaunch gun. In this version, in the atmosphere, the discardable shell protects the device. (John Hunter/Quicklaunch/Google Tech Talks).

4. Designing the Gun

First, we choose the principle of the gun. Electromagnetic gun at a cost will be more than $200 M, as it is associated with large problems with complexity and wear resistance. The maximum speed of 5.5 km/s is not sufficient for launching into space. The hydrogen gun is much cheaper and can reach much higher speeds than the electromagnetic analog.

Gunpowder is the weakest bidder for achieving space, with its maximum speed of 3 km/s and pollution problems. For the hydrogen gun, the world record for the speed is 11.2 km/s, established in 1966, due to the low molecular weight of hydrogen and hence the high speed of sound. The orbital speeds of 7.6 km/s of launching objects are also suitable for a hydrogen gun, launching a single-stage rocket into a circular orbit.

Based on this, the most rational choice is the gas circuit of the gun. As a prototype, the Quicklaunch project is used. Marine basing for greater stability and noise immunity can be improved by covering the gun with ice, which will also facilitate its guidance and transportation.

Assumed parameters, the diameter is 1 meter, the speed of the projectile, which has weight 100 kg, 6 km/s, Length-1,100 m. Hydrogen in the combustion chamber is heated from 280 degrees Kelvin, at a pressure of 600 psi (41 at atm.), Up to 700 degrees Kelvin, at a pressure of 2 kpsi (136 atm.).

The problem of overheating of the projectile during the passage of dense layers of the atmosphere is solved by installing a thermal insulation coating, a thickness of 5 inches in front, and 1 inch on the sides and behind. The speed loss will be 500 m/s.

Control and further acceleration to 7.6 km/s is accomplished by rotating the projectile, installing a liquid fuel engine as a first stage and having control systems with GPS. The payload will be 20-28%, in contrast to 1-2% for conventional missiles.

The schematic of a gas gun is shown in Fig. 4. It consists mainly of a gun barrel in which a projectile is accelerated by high pressure light gas acting on the projectile back.

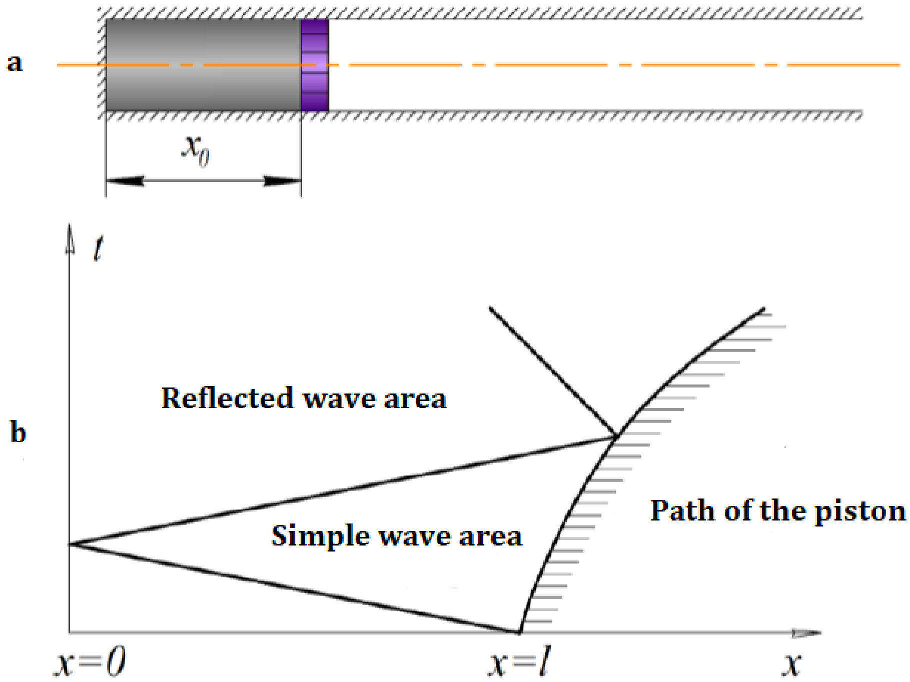

Fig. 4 Lagnange problem: a—design task scheme; b—wave propagation pattern.

First, we find the pressure in the chamber before and after heating by the Van der Waals equation, where for hydrogen a = 0.0245 N·m^4/mol^2, b = 26.653 cm^3/mol. The mass of the gas is taken as m = 800 kg. The volume of gas in the chamber is v = 280 m^3. The relative molecular weight of hydrogen is n = 0.002 kg/mol.

The universal gas constant r = 8.31 J/mol·K.

For temperature T = 700 K:

$$p = \frac{\left(\frac{m \cdot r \cdot T}{n}\right)}{\left(v - \frac{m \cdot b}{n}\right)} - \left(\frac{m}{n}\right)^2 \cdot \frac{a}{v^2} = 1.05 \cdot 10^8 \, \text{Pa}$$

For temperature T = 280 K:

$$p = \frac{\left(\frac{m \cdot r \cdot T}{n}\right)}{\left(v - \frac{m \cdot b}{n}\right)} - \left(\frac{m}{n}\right)^2 \cdot \frac{a}{v^2} = 4 \cdot 10^7 \, \text{Pa}$$

Adiabatic index for hydrogen k = 1,387. Caliber r = 0.5 m. The area of the trunk channel is in this case equal to S = 0.785 m^3. The length of the chambers l_0 = v/s.

To calculate the length of the barrel, the velocity of the projectile and its time in the barrel, the Lagrangian problem for the region of a simple wave is solved, so further the solution does not make a significant contribution to the result and has no analytical solutions.

And t_2-the time of finding the projectile in the barrel channel, after which the mirrored from the bottom of the barrel under pressure wave overtakes the projectile and the solution leaves the region of a simple wave.

$$t_2 := \frac{l_0}{c_0} \cdot \left(2 + \frac{k+1}{2k} \cdot \frac{M}{m0}\right) = 0.15 \, \text{s.}$$

At time t = 0.15 s.

After integrating equation of motion of the projectile, we get speed of the projectile as a function of time.

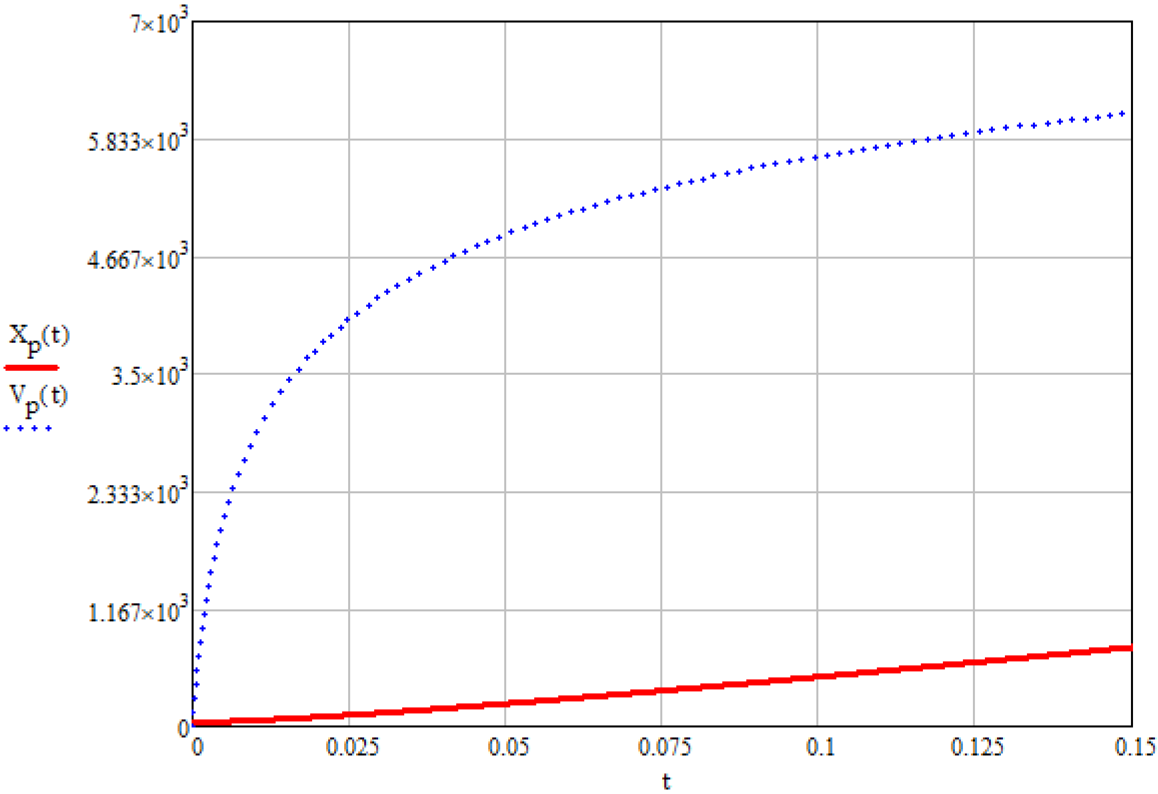

Fig. 5 The velocity and pathway of the projectile in the barrel channel versus time.

$$V_p(t) = \frac{2}{k-1}\cdot\left(\frac{k\cdot p_0}{\rho_0}\right)^{\frac{1}{2}}\cdot\left[1-\left[1+\frac{S\cdot t}{m0}\cdot\left(k\cdot p_0\cdot\rho_0\right)^{\frac{1}{2}}\cdot\frac{k+1}{2k}\right]^{-1\cdot\left(\frac{k-1}{k+1}\right)}\right] = 6088\ \mathrm{m/s}$$

This equation when integrated gives the location X of the projectile in the gun barrel.

$$X_p(t) = l_0 + \frac{2t\cdot\left(\frac{k\cdot p_0}{\rho_0}\right)^{\frac{1}{2}}}{k-1} + 2\frac{k}{k-1}\cdot\frac{m0}{\left(\rho_0\cdot S\cdot l_0\right)}\cdot l_0\cdot\left[1-\left[1+\frac{k+1}{2k}\cdot\frac{\rho_0\cdot S\cdot l_0}{m0}\cdot\frac{t}{l_0}\cdot\left(\frac{k\cdot p_0}{\rho_0}\right)^{\frac{1}{2}}\right]^{\frac{2}{k+1}}\right] = 786.4\ \mathrm{m}$$

Therefore, the length of the trunk should be taken 800 m.

5. Conclusions

As a result, it turned out to be a project of a light gas gun, capable of delivering a useful cargo of 100 kg and a diameter of 1 m, including the first stage for acceleration from 5.5 km/s to 7.6 km/s, to low Earth orbit. As the launched objects, modern small satellites will be suitable, which are produced in a large number of private companies. Various electronics, sensors can withstand loads without any problems. The main problem of distant missions, the delivery of fuel into orbit for further rocket flight from orbit to other satellites and planets can also be solved. For these purposes, the barrel system will fit perfectly, accumulating fuel at the station in orbit, while spending $500 per kilogram of cargo in orbit, instead of the current \$2-10 k. The only obstacle to the project is financing: despite all the prospects to become a new technological breakthrough in the space sphere and saving billions of dollars from each program (\$5 billion per person for the flight to the moon only for fuel), this sphere is almost not developing. The market for space guns exists, but so far virtual, since no one believes in success.

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