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New Small Cheap Rocket for Small Payload

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***Abstract*— Conventional modern rocket has existed for more than a half century. However, there has been little or no significant progress in their basic data. They are very exceedingly complex and generally very expensive to build. Designers ordinarily try to improve them by simplifying in order to reduce the cost payload launches. They try to use the first stagy of rocket sometimes, because the rocket engine and body are expensive. But no significant success.**

The author offers a new type of rocket which does not have the usual rocket body and engine (only open solid rocket fuel). This new rocket is cheap to fabricate, may be switched on and switched off many times and has specific impulse more than conventional solid fuel engine (i.e., close to liquid fuel). One can be used for launch as well as vector correcting rocket.

This method is particularly suitable for micro-spacecraft (up to 1 kg). It allows to reduce the launch weight of the rocket to 50 ÷ 1000 kg.

***Index Terms*— non-body rocket, unusual rocket, explosive rocket propulsion, AB rocket.**

I. INTRODUCTION

At the present time, two main propulsions are used in rocket launch systems: liquid and solid fueled engines. They transform chemical energy in gas pressure in shaped special combustion chambers, the gas flows out of the chamber and creates a thrust which propels the rocket. The more the gas pressure put into the chamber, the more propulsion efficiency, but incidentally the more complex the system becomes and the more mass of rocket required. That way the pressure into chamber is limited to about 200 atm. The typical liquid and sold fuel engines are sown in fig. 1-2.

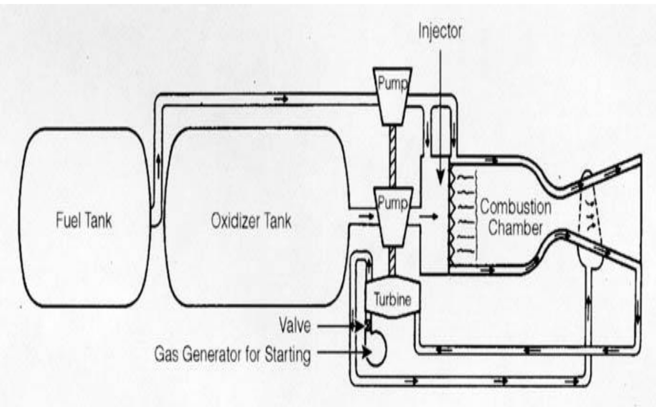

Fig.1. Typical liquid rocket engine.

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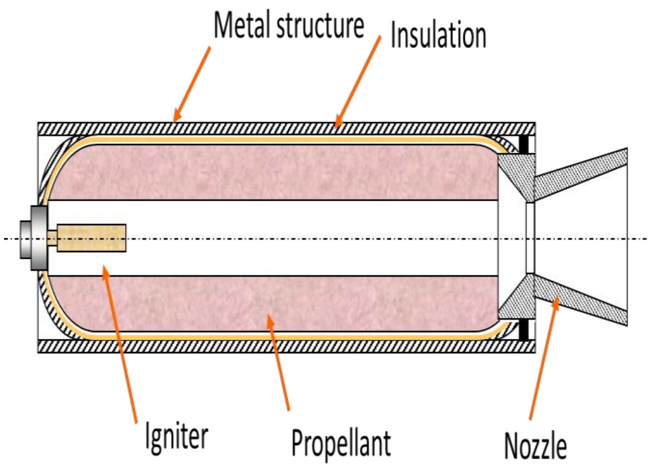

Fig.2. Typical solid fuel rocket engine. No shutdown of the engine is possible.

The liquid engine is very expensive (tens of millions of dollars). Owners want to save it and reuse it again to spread the expense. This helps only a little. The recovery landing system is complex, has weight and needs an additional engine. That decreases the payload attainable.

The solid fuel rocket engine has low impulse and very high mass because it has a big combustion chamber having high pressure and hot gases. Specific impulse solid rocket engine about 2200-2800 m/s, liquid engine about 3000-3200 m/s, liquid hydrogen up 4000 m/s. But liquid hydrogen needs to be a very large volume and maintained in liquid form by cryogenic temperature refrigeration or insulation. Generally-speaking, it is only used in upper rocket stage.

II. DESCRIPTION OF INNOVATIONS

The offered rocket is shown in Fig.3. One contains: *a, b, c, d* -different versions of the offered rocket, *f* – detail fuel layer; 1 – head of rocket, 2 – light cover of fuel, 3 - solid fuel layers, 4 – control of the trajectory direction and rotation of rockets; 5 – partition which separated solid fuel layers, 6 - heat insulator, shock absorber, 7 – explosion fuel layer, 8 - ignition net.

Form "*a*" allows to launch the rocket with constant acceleration. That may be important when we launch the frail people with weak constitutions. The conventional rocket has a constant thrust. When fuel burn out their acceleration increases. Form *"b"* allows in advance to programming the thrust. Version *"c"* has stabilizer which allows to change the direction of thrust and rotates rocket. Version *"d"* has non-burn thin fuel cover which can improve efficiency in hard vacuum of outer space.

The fuel layer *"f"* has light partition 5, which protects the next top layer from explosion. The heat insulator 6 protects the next top layer from heat, hot gas and shock wave. The fuel layer has an explosive layer 7 and an ignition net 8.

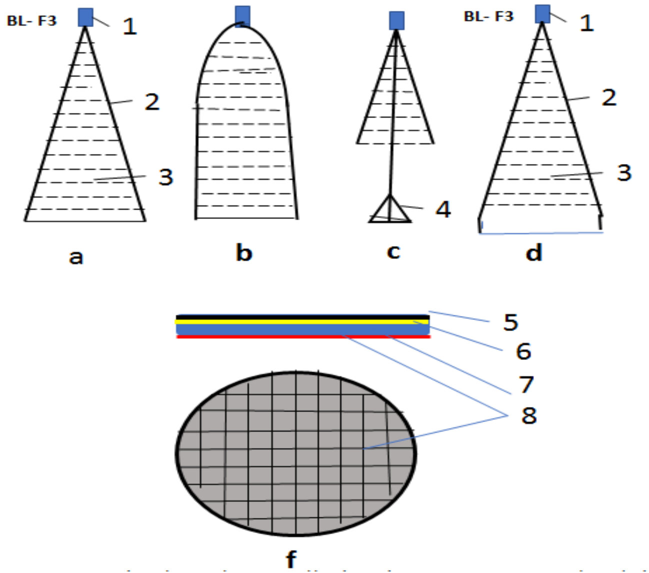

Fig.3. Suggested Rocket without usual body and engine.

Notations: a, b, c, d -different versions of the offered rocket, *f* – fuel layer; 1 – head of rocket, 2 – light cover of fuel, 3 - solid fuel layers, 4 – control of the trajectory direction and rotation; 5 – partition which separated solid fuel layers, 6 - heat insulator, shock absorber, 7 – layer of explosive, 8 - ignition net.

The unique and unusual rocket offered works in a different way. The ignition net has high resistance in wire contact and ignites the fuel layer on all surface simultaneously. The fuel layer instantly burns and creates the gigantic (maximum possible) pressure (some thousand atmospheres) and some thousands degree of temperature (see section "Theory"). Other engineers can only dream about such engines! The combustion chamber was destroyed by this pressure in any conventional engine. But offered rocket does not have the combustion chamber and accumulating exposed gas will be thrown out with maximum speed. The explosive layer is thin and gas will be thrown out in one direction with maximum speed (maximum impulse).

We can, any time, switch "on" or switch "off" the offered rocket's thrust. We can control in very big diapason if we change the frequency of electric impulses. It is impossible in conventional solid fuel rocket engine and not acceptable in liquid engine because we would have lost the efficiency of the old-fashion rocket engine.

III. Advantages and Disadvantages of the Offered Rocket

The offered rocket has numerous advantages in comparison with the current liquid and solid fuel rocket types:

1. The proposed rocket is **cheap**. There is no expensive or heavy engine and associated units. In fact, this is the cost of an explosive or solid rocket fuel.

2. The proposed rocket is **very simple**. It can be produced by a non-industrial country that bought explosives or solid rocket fuel.

3. Its **minimum payload is not limited** by the weight of an ordinary rocket engine. It can even be a fraction of a gram. Therefore, with the help of the proposed rocket, micro-vehicles with huge interplanetary velocities can be launched.

4. The proposed missile does **not have an expansion nozzle**. Therefore, high-performance metal rocket fuels can be used in it. In the nozzle of an ordinary rocket engine, a rocket fuel, containing metals, condenses and eats up their effectiveness (see below).

5. If the fuel layer is slightly concave, then the proposed missile **can be used as** an effective anti-satellite cumulative space **weapon**.

6. In the proposed rocket, the discharge of spent stages (coating of fuel layers. **No stages**) occurs continuously. In conventional multi-stage rockets, individual stages are discarded only after the total consumption of fuel in them, which reduces the effectiveness of conventional missiles.

7. Using in top part of the offered rocket the more **efficient fuel layers** (but more expensive) we can improve the payload mass without significant cost of rocket.

8. No combustion chamber.

Possible fear and objection.

1. A shock wave from the first layer can cause an explosion of the entire rocket.

Objection: Conventional solid-fuel missiles are widely used and do not explode, but are quietly burning in layers. Everything depends on the properties of the fuel (explosives). There are explosives that do not even respond to blows.

IV. Theory

The most important characteristic of any rocket engine is the outflow speed of combustion products, the expanding gases creating thrust. If we know the specific energy of fuel, the maximum outflow speed is:

$$\text{From } E = \frac{m}{2}V^2, \text{ we get } V = \sqrt{\frac{2E}{m}}\ , \qquad (1)$$

where E is energy, J; m is mass of fuel, kg; V is speed of exhaust gas, m/s. $E/m = E_s$ is energy of 1 kg fuel (specific energy of fuel). Example, for typical $E_s = 4 \cdot 10^6$ J/kg, $V = V_o$ = 2820 m/s. For this unusual offered rocket the speed of an exhaust gas must be corrected by coefficient $k_c = m_f/m_l \cong 0.92 \div 0.98$, $V_o = k_c V$, where m_f is mass of one layer of fuel, kg; m_l is full mass of layer include fuel, partition, thermal insulation and ignition net.

The maximum of temperature the instantaneous explosion of fuel is

$$T = \frac{m_1 V^2}{k}\ , \qquad (2)$$

where T is gas temperature, K; $m_1 = \mu \cdot m_p$ is mass of one molecule exhaust gas, kg; μ is molar weight, $m_p = 1.67\times10^{-27}$ is proton mass, kg; $k = 1.38\times10^{-23}$ is Boltzmann constant, J/K. If gas is CO_2 for above example (V = 2820 m/s, μ = 4+16×2 = 46) we get T =14.84×10^3 K.

The maximum gas pressure is

$$P = nkT\ , \quad n = y/\mu \cdot m_p\ , \qquad (3)$$

where P is gas pressure, N/m^2: n is number of molecules of exhaust gas in one m^3; k is Boltzmann constant, J/K; T is gas temperature, K; y is specific weight of explosive, kg/m^3. If y = 2000 kg/m^3, for our example we get maximum pressure 17.7×10^3 atm.

The final speed of offered rocket is

$$V_f = V_o \ln(M_o/M_p) \quad (4)$$

where V_f is final speed, m/s; M_p is payload, kg; M_o is started weight of rocket, kg.

V. Application for micro-spacecraft

This method is particularly suitable for micro-spacecraft (up to 1 kg). It allows to reduce the launch-weight of the rocket to 100 ÷ 1000 kg.

It is known that to enter the orbit of the Earth, the Sun and beyond the solar system when starting from the Earth in an airless atmosphere, the space spacecraft must have the following minimum speeds:

1. To low (100 km) circle Earth orbit V = 7.93 km/s.
2. To Sun orbit V = 11.16 km/s.
3. To exit from this Solar System V = 16.67 km/s.

To overcome the resistance of the atmosphere and climb to a stationary orbit (100 km) above the von Karman Line, we must add to this speed about 2 to 3 km/s. This addition is the smaller for the higher initial acceleration.

In our 20th Century of great successes in micro-electronics and micro-devices, it is unreasonable to spend huge amounts of money and send a person into space and other planets with a heavy, complex and dangerous life-support system, when the data which are interesting us, we can obtain by the use of micro-chips and micro-sensors instead of human flesh “flying” dangerously! Already complex, “reasonable” computers the size of wheat grain and energy issue have been created, even patented.

The same can be said about military equipment. Why send a multi-ton rocket, when to disable a power plant it’s enough to damage a vital control node.

Estimations. Let us, estimate some important data. Below are presented some estimations for micro-spacecraft weighing 1 kg and typical rocket specific impulse 2800 m/s.

1). Maximum speed (without air drag and gravitation) by Equation (4):

For M_o = 1000 kg, V_f = 19.3 km/s;
for M_o = 500 kg, V_f = 17.4 km/s;
for M_o = 250 kg, V_f = 15.4 km/s;
for M_o = 100 kg, V_f = 12.9 km/s;
for M_o = 50 kg, V_f = 11.5 km/s.

The air-drag and Earth gravitation requests 2 – 3 km/s additional speed. As you see the offered rocket allows the rocket having the start mass M_o = 50 – 100 kg launch the micro-satellites (up 1 kg) to LEO (Low Earth Orbit); having start mass M_o = 250 kg launch the micro-satellites (up 1 kg) to other solar planets (Mars, Venus). The offered rocket having start mass more 1 metric ton can leave our Solar System [7] Ch.8.

The loss of speed in gravitation on vertical part of trajectory for acceleration (10 ÷ 20)g_o is about 500 ÷ 300 m/s.

Let us estimate the energy.

Lifting 1 kg up altitude H = 100 km = 100,000 m request energy

$$E_H = g_o \cdot m \cdot H \sim 10 \cdot 1 \cdot 10^5 = 1 \cdot 10^6 \text{ J},$$

where g_o = 9.81 m/s^2 is Earth acceleration at H = 0.

Acceleration the m = 1 kg mass to speed V = 8000 m/s request energy

$$E_a = mV^2/2 = 1 \cdot 8000^2/2 = 32 \cdot 10^6 \text{ J},$$

The loss of energy from air drag conventionally is found by integration of the drag on way. In supersonic flow the wave drag is main hinderance. One may be computed by equation:

$$F = C_d \rho a V S/2,$$

where F is drag force, N; C_d is coefficient of wave drag, $C_d = 2\theta^2$, θ is edge angle, rad.; ρ is air density kg/m^3, a is sound air speed, m/s; V is rocket speed, m/s; S is cross-section of rocket, m^2.

VI. Solid propellant

Solid propellant for current rocket engine

Since solid-fuel rockets can remain unused in proper storage for long time periods, and then reliably launch on short notice, they have been frequently used in military applications such as war missiles. Solids are, however, frequently used as strap-on boosters to increase payload capacity. Solid rockets are used as light launch vehicles for low Earth orbit (LEO) payloads under 2 metric tons or escape payloads up to 500 kilograms.

A typical, well-designed ammonium perchlorate composite propellant (APCP) first-stage motor may have a vacuum specific impulse (I_{sp}) as high as 285.6 seconds (Titan IVB SRMU). This compares to 339.3 s for kerosene/liquid oxygen (RD-180) and 452.3 s for hydrogen/oxygen (Block II SSME) bipropellant engines.

Solid rockets can provide high thrust for relatively low-cost. For this reason, solids have been used as initial stages in rockets (for example the retire US Space Shuttles as boosters), while reserving high specific impulse engines, especially less massive hydrogen-fueled engines, for higher altitude staging. In addition, solid rockets have a long history as the final boost stage for satellites due to their simplicity, reliability, compactness and reasonably high mass fraction. A spin-stabilized solid rocket motor is sometimes added when extra velocity is required, such as for a mission to a comet or the outer solar system, because a spinner does not require a guidance system (on the newly added stage).

Higher performing solid rocket propellants are used in large strategic missiles (as opposed to commercial launch vehicles). HMX, $C_4H_8N_4(NO_2)_4$, a nitroimine with greater energy than ammonium perchlorate, was used in the propellant of the Peacekeeper ICBM and is the main ingredient in NEPE-75 propellant used in the Trident II D-5 Fleet Ballistic Missile. The Naval Air Weapons Station at China Lake, California, developed a new compound, $C_6H_6N_6(NO_2)_6$, called simply CL-20 (China Lake compound #20). Compared to HMX, CL-20 has 14% more energy per mass, 20% more energy per volume, and a higher oxygen-to-fuel ratio. Its cost comes down, be suitable for use in commercial launch vehicles, with a very significant increase in performance compared with the currently favored APCP solid propellants. With a specific impulse of 309 s already demonstrated by Peacekeeper’s second stage using HMX propellant, the higher energy of CL-20 propellant can be expected to increase specific impulse to around 320 s in similar ICBM or launch vehicle upper stage applications, without the explosive hazard of HMX.[21]

An attractive attribute for military use is the ability for solid rocket propellant to remain loaded in the rocket for long durations and then be reliably launched nearly at a moment’s notice.

Some popular solid propellants used now are following:

1. **Black powder** (gunpowder) is composed of charcoal

(fuel), potassium nitrate (oxidizer), and sulfur (fuel). It is one of the oldest pyrotechnic compositions with application to rocketry. In modern times, black powder finds use in low-power model rockets (such as Estes and Quest rockets), as it is cheap and fairly easy to produce.

2. In general, **rocket candy** propellants are an oxidizer (typically potassium nitrate) and a sugar fuel (typically dextrose, sorbitol, or sucrose) that are cast into shape by gently melting the propellant constituents together and pouring or packing the amorphous colloid into a mold. Candy propellants generate a low-medium specific impulse of roughly 130 s and, thus, are used primarily by amateur and experimental rocketeers.

3. **Double base** (DB) propellants are implemented in applications where minimal smoke is required yet medium-high Double performance (I_{sp} of roughly 235 s) is required. The addition of metal fuels (such as aluminum) can increase the performance (around 250 s), though metal oxide nucleation in the exhaust can turn the smoke opaque.

VII. Composite propellants

A powdered oxidizer and powdered metal fuel are intimately mixed and immobilized with a rubbery binder (that also acts as a fuel). Composite propellants are often either ammonium nitrate-based (ANCP) or ammonium perchlorate-based (APCP). Ammonium nitrate composite propellant often uses magnesium and/or aluminum as fuel and delivers medium performance (I_{sp} of about 210 s) whereas ammonium perchlorate composite propellant often uses aluminum fuel and delivers high performance (vacuum I_{sp} up to 296 s with a single piece nozzle or 304 s with a high area ratio telescoping nozzle). Ammonium dinitramide, $NH_4N(NO_2)_2$, is being considered as a 1-to-1 chlorine-free substitute for ammonium perchlorate in composite propellants.

Polyurethane-bound aluminum-APCP solid fuel was used in the submarine launched Polaris missiles. APCP used in the retired US Space Shuttle Solid Rocket Boosters consisted of ammonium perchlorate (oxidizer, 69.6% by weight), aluminum (fuel, 16%), iron oxide (a catalyst, 0.4%), polybutadiene acrylonitrile (PBAN) polymer (a non-urethane rubber binder that held the mixture together and acted as secondary fuel, 12.04%), and an epoxy curing agent (1.96%). It developed a specific impulse of 242 seconds (2.37 km/s) at sea level or 268 seconds (2.63 km/s) in a vacuum. The 2005-2009 Constellation Program was to use a similar PBAN-bound APCP. In 2009, a group succeeded in creating a propellant of water and nano-aluminium (ALICE).

VIII. High-energy composite (HEC) propellants

Typical HEC propellants start with a standard composite propellant mixture (such as APCP) and add a high-energy explosive to the mix. This extra component usually is in the form of small crystals of RDX or HMX, both of which have higher energy than ammonium perchlorate. Despite a modest increase in specific impulse, implementation is limited due to the increased hazards of the high-explosive additives.

Composite modified double base propellants

Composite modified double base propellants start with a nitrocellulose/nitroglycerin double base propellant as a binder and add solids (typically ammonium perchlorate (AP) and powdered aluminum) normally used in composite propellants. The ammonium perchlorate makes up the oxygen deficit introduced by using nitrocellulose, improving the overall specific impulse. The aluminum improves specific impulse as well as combustion stability. High performing propellants such as NEPE-75 used to fuel the Trident II D-5, SLBM replace most of the AP with polyethylene glycol-bound HMX, further increasing specific impulse. The mixing of composite and double base propellant ingredients has become so common as to blur the functional definition of double base propellants.

IX. Minimum-signature (*smokeless*) propellants.

One of the most active areas of solid propellant research is the development of high-energy, minimum-signature propellant using $C_6H_6N_6(NO_2)_6$ CL-20 nitroimine (China Lake compound #20), which has 14% higher energy per mass and 20% higher energy density than HMX. The new propellant has been successfully developed and tested in tactical rocket motors. The propellant is non-polluting: acid-free, solid particulates-free, and lead-free. It is also smokeless and has only a faint shock diamond pattern that is visible in the otherwise transparent exhaust. Without the bright flame and dense smoke trail produced by the burning of aluminized propellants, these smokeless propellants all but eliminate the risk of giving away the positions from which the missiles are fired. The new CL-20 propellant is shock-insensitive (hazard class 1.3) as opposed to current HMX smokeless propellants which are highly detonable (hazard class 1.1). CL-20 is considered a major breakthrough in solid rocket propellant technology but has yet to see widespread use because costs remain high.

X. Electric solid propellants

Electric solid propellants (ESPs) are a family of high performance plastisol solid propellants that can be ignited and throttled by the application of electric current. Unlike conventional rocket motor propellants that are difficult to control and extinguish, ESPs can be ignited reliably at precise intervals and durations. It requires no moving parts and the propellant is insensitive to flames or electrical sparks.

XI. Modern fuel mixtures

Mixed solid fuels (CTT) are a mixture of solid fuel and oxidant. There are a large number of different mixtures suitable for successful rocket engineering. Typically, they are all created around a small number of effective solid oxidants, which combine with a variety of combustible substances. The most well-known oxidants are:

As fuel used:

• metals or their alloys (aluminum, magnesium, lithium, beryllium), metal hydrides.

• polymers and resins (polyethylene, polyurethane, polybutadiene, rubber, bitumen).

• Other substances, for example polysulfides, boron, carbon.

In modern solid-fuel heavy-duty engines, a mixture of ammonium perchlorate with aluminum and rubbers is most often used. Sometimes polyurethane is used instead of rubbers, which allows increasing the shelf life of the TPT checker and increasing its rigidity, but at the expense of manufacturability. Aluminum is the main source of thermal energy due to the high calorific value of the oxidation reaction. However, due to the high boiling point, the alumina in the jet is solid rock solid and does not perform thermodynamic work during expansion in the nozzle. Therefore, the main source of gaseous products is the polymer binder. The admixture of solid combustion products TPT increases the internal friction in the jet stream of gases, which reduces the efficiency of the operation of the solid propellant. The specific impulse of such fuel is about 250-280 seconds.

XII. Explosives General characteristics

Any explosive has the following characteristics:
• ability to exothermic chemical transformations.
• the ability to self-propagating chemical transformation.
The most important characteristics of explosives are:
• speed of explosive transformation (velocity of detonation or burning rate),
• detonation pressure,
• heat (specific heat) of the explosion,
• composition and volume of explosive gas products,
• the maximum temperature of the products of the explosion (explosion temperature),
• sensitivity to external influences,
• critical detonation diameter,
• critical density of detonation.

During ignition, the decomposition of explosives occurs so rapidly (during a time from 10^{-6} to 10^{-2} s) that the gaseous decomposition products, with a temperature of several thousand degrees, becomes compressed in a volume close to the initial charge volume. Sharply expanding, they are the main primary factor of the destructive effect of the explosion.

There are two main types of action of explosives: blasting (local action) and high explosive (general action). The stability of storage of explosives and their handling is of great importance.

In application, no more than two or three dozen explosives and their various mixtures are ever widely used. The main characteristics of the most common are summarized in the following Table 1 (data are given for a charge density of 1600 kg/m^3):

Table 1. Explosive.

Explosive substance	Oxygen %	Heat of explosive MJ/kg	Volume of explosion products, м^3/кг	Detonation velocity, км/s
TNT	-74,0	4,2	0,75	7,0
Tetryl	-47,4	4,6	0,74	7,6
Hexogen	-21,6	5,4	0,89	8,1
Ten	-10,1	5,9	0,79	7,8
Nitroglycerine	+3,5	6,3	0,69	7,7
Ammonite No6	0	4.2	0.89	5.0
Ballistic power	-45	3.56	0.97	7.9

Calorific value of some chemical reaction in Table 2 below.

Table 2. Calorific value of some chemical reactions (MJ/kg) and Specific impulse (km/s)

Fuel/ Oxidizer	C	H_2	Li	Be	B	Mg	Al	Si
Oxygen MJ/kg km/s	8.967 4.23	13.45 5.18	19.94 6.31	24.43 6.99	18.27 6.04	14.79 5.44	16.34 5.72	14.08 5.31
Fluorine MJ/kg km/s	7.751 3.94	13.45 5.18	23.67 6.88	20.24 6.36	12.61 5.02	17.64 5.94	15.54 5.57	14.54 5.39

Note: the gas and liquid components can be used in offered rocket as compressed gas and liquid in micro-capsules like a solid fuel.

In reality these values are lower because in given elements are used in chemical connection in other elements.

XIII. Discussion

The proposed unusual rocket greatly simplifies factory production, reduces the cost of the rocket and reduces the cost of launching the payload. It allows an at will turn "on" and "off" the thrust many times. It does not need to return to the Earth an expensive liquid engine (its absence) and allows one-stage launch of micro satellites at sufficiently high speeds.

The production of such rocket is based on well-developed technologies for solid rocket fuels and explosives. The rocket does not have a nozzle and can burn highly effective metal powder additives. The missile has one stage, but is capable of using more efficient fuels at the final stage of flight.

It can be produced by low-industrial countries. The current solid rocket fuel can be used for offered rocket if we add a small amount of the combustion accelerator to the fuel, if and whenever necessary.

Acknowledgement

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