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Hybrid Propulsion with Efficient Fueling System for Spacecraft

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Abstract: Current space launch vehicles use chemical reactions (solid and liquid propellants) to achieve sufficient thrust to launch spacecraft. They carry a lot of fuel to escape the Earth's gravity. For long-distance space-travel, more fuel is required. But more fuel increases the weight of the spacecraft and to minimize fuel consumption, the need for fuel-efficient spacecraft is necessary. It can make the deep-space manned mission possible. The ratio of payload and the overall weight of spacecraft are uneven; that means, to carry one ton of mass in space we require more than 100 tons of launch mass. For space colonization, space rockets should be able to carry a higher percentage of human beings with it. Currently, due to the overall weight and design of the spacecraft, it is not possible to carry number of people. Through the above mentioned four techniques, we can save the fuel of spacecraft at a large extent and can reduce its fuel consumption.
Keywords: thrust, Spacecraft, fuel, deep-space

I. INTRODUCTION

In today's space technology, with any current source of propulsion like - electrical power, chemical, nuclear or solar, the maximum amount of power that can be generated limits the amount of thrust to a small value. Power generation adds significant mass to the spacecraft and ultimately the weight of the power source limits the performance of the vehicle.

The ratio of payload and the overall weight of spacecraft are uneven; that means, to carry one ton of mass in space we require more than 100 tons of launch mass [1]. For space colonization, space rockets should be able to carry a higher percentage of human beings with it. Currently, due to the overall weight and design of the spacecraft, it is not possible to carry number of people [2].

Currently, the bell shaped rocket engines in spacecraft is used for take-off. The large fuel cylinders increase the weight of the spacecraft and hence lower payload can be taken. This increases the required fuel and the overall cost for the space mission [2].

Chemical propellants are currently used for thrusters; high value of thrust is obtained from the heated gas. Another important factor is the density of a propellant, a given weight of dense propellant can be carried in a smaller and lighter tank than the same weight of a low-density propellant. Liquid hydrogen, for example, is energetic and its combustion gases are light. However, it requires very large tanks to carry [3].

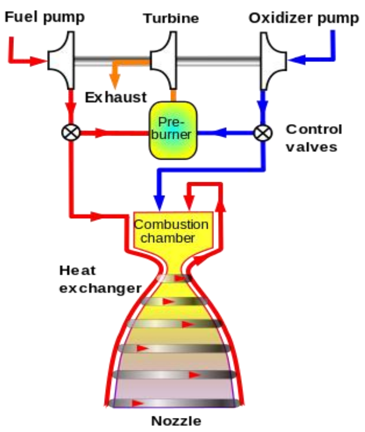

Fig 1. Gas Generator Rocket Cycle
Source: Adapted from [4]

The above-shown figure (fig 1) describes a Gas generator rocket cycle which is currently in use for the rockets to burn up the fuel and create hot gas for propelling it forward. These gas generators create a lot of fumes as well as debris in the space when the stage is used up which is very toxic to the environment.

II. PROBLEM FORMULATION

Producing power for spacecraft without affecting our environment is a continuing challenge. Fossil fuels like gasoline, coal, and jet fuel are not renewable, and burning these fuels increases air pollution and harms the environment. The cost of the spacecraft's fuel is very expensive. For the spacecraft to carry higher payload and travel further, a very large amount of fuel is required which unnecessarily increases the weight of the spacecraft. The various stages of a spacecraft carry the fuel, when the fuel is used up the stage is discarded in the space, which creates a lot of space debris. To carry out deep space missions, we need a lot of fuel so the efficient use of fuel is necessary with more powerful propulsion engines.

III. IMPACT ON THE SOCIETY

Every time a rocket launches, it produces a plume of exhaust in its wake that leaves a mark on the environment. These plumes are filled with materials that can collect in the air over time, potentially altering the atmosphere in dangerous ways. Rockets that run on solid propellants produce a higher amount of alumina particles, a combination of aluminum and oxygen that is white and reflective. Most orbital rockets don't run on solid propellants these days, though some launch companies like the United Launch Alliance do add solid rocket boosters to vehicles to give them extra thrust. Meanwhile, rockets that run on liquid kerosene, a type of refined oil, produce more of the dark soot particles, what is known as black carbon. So by the use of "green" fuel, we can reduce the effect of spacecraft's harmful gases in the environment. With the green propellant, launch vehicle and spacecraft fuel loading will be safer, faster and much less costly. This fuel-saving will be beneficial for society.

IV. DESIGN APPROACH AND NOVELTY

Different design approaches can be implemented in the spacecraft to make it more fuel-efficient as well as convenient for deep-space mission:

A. Aerospike engine Rocket Spacecraft

The futuristic spacecraft needs single staged reusable rocket engines which can be use for deep space missions. For this, the use of aerospike engine with the efficient propellant methodologies can improve the space exploration for the future.

The main advantage of aerospike rocket engines is that, it can maintain its aerodynamic efficiency across a wide range of altitude. It belongs to the altitude compensating nozzle engine. A spacecraft with an aerospike engine can use 25-30% less fuel at low altitude, where most of the missions have the greatest need for thrust. Aerospike engines are single stage to orbit design engines which we can consider best for the spacecrafts [11].

Currently, the spacecraft which are being launched in the space uses multiple rockets. These spacecraft require a lot of fuel and its weight is much higher for the payload being carried. because of this, spacecraft with self-launching capability needs to be developed. These spacecraft will not have any supporting rocket to take it out of the atmosphere; instead it will take-off on its own. This spacecraft with horizontal takeoff system can reduce the requirement of excess fuel and can reach a certain altitude like a normal aircraft. After achieving the altitude, the thrusters can increase the power to enter the Earth's LEO. After entering the orbit the substitute thruster can initiate further movement in the space.

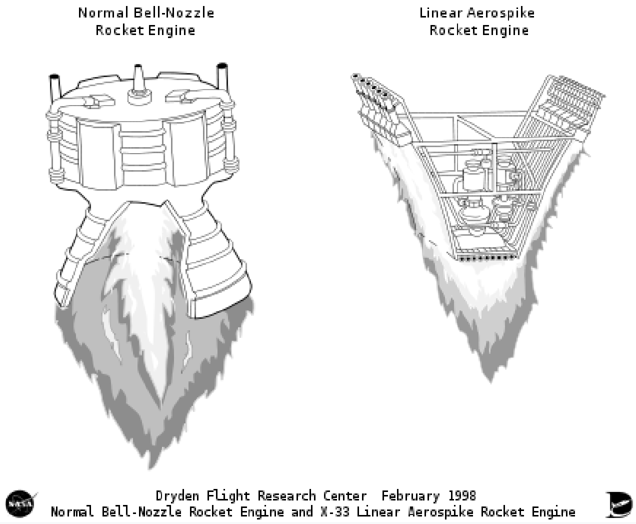

Fig 2. Comparison between the design of a bell-nozzle rocket (left) and an aerospike rocket (right)
Source: Adapted from [11]

B. Green Fuel for Spacecraft

A non-toxic liquid could fuel the spacecraft and propel missions to the deep space. The propellant as proposed- blends hydroxyl ammonium nitrate with an oxidizer that allows it to burn easily creating an alternative to hydrazine, the fuel which is currently in use by spacecraft. The spacecraft can be filled up with fuel when it is being manufactured, hence resulting in the saving of cost. The propellant drastically increases the performance. It's denser than hydrazine and offers nearly 50% better performance. This means spacecraft can travel farther or operate for longer with less propellant onboard. A different set of hardware is to be used for the use of green fuel. This fuel is developed by the Air Force Research Laboratory (AFRL) at Edwards Air Force Base in California [5].

C. Ion Thrusters

An Ion thruster is a special type of electric propulsion used in spacecraft which generates the thrust by accelerating cat-ions by utilizing electricity. An on thruster is one of the best available techniques of propulsion in terms of cost, speed and the distance covered per-used fuel.

The only drawback they have is that it cannot be used inside the atmosphere as there are already available ions in it. This produces none to very minimum thrust which is not enough to overcome the air resistance and reach the escape velocity required for the spacecraft to escape the Earth's atmosphere. Spacecraft rely on conventional chemical rockets to initially reach orbit as discussed previously in current status and challenges [6].

The working of ion thruster is fairly simple. It consists basically of three components: the plasma generator, the accelerator grids, and the neutralizer cathode [7].

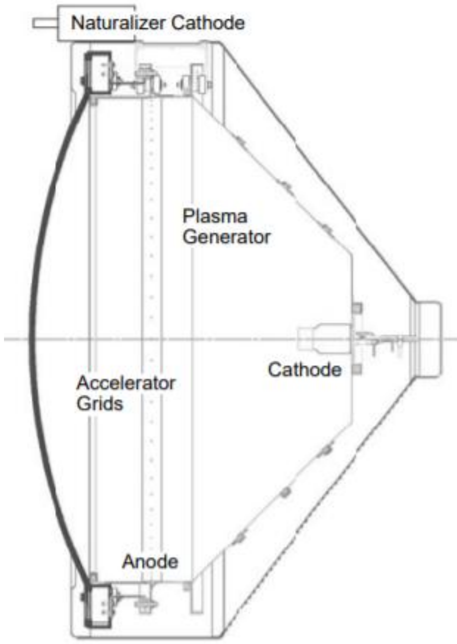

Fig 3. Ion thruster schematic showing grids, plasma generator and neutralizer cathode
Source: Adapted from [7]

The above figure (fig 3) shows a schematic of an electron-bombardment ion thruster that uses an electron discharge to generate the plasma. The thrust beam is formed by the discharged cathode and anode; which is the plasma generator. The plasma generator thus produces the thrust to propel the spacecraft forward [7].

D. Air-breathing electric propulsion

An air-breathing electric propulsion (ABEP) technique with ion pump uses gases from the outer fringes of planets to accelerate the spacecraft.

There is a gas collector installed in the inlet of ABEP, which entraps the gas molecules from the space and compresses the gas molecules to store it. An ion thruster is used as a technique of propulsion such that the compressed gas captured by the gas collector will be used for its ignition.

The figure shown alongside (fig 5 and fig 6) shows the propulsion technique in action. In fig 5, a xenon propellant is used for ion propulsion. The ignition takes place with the help of collected compressed gas.

In fig 6, the direct use of air propellant is shown. The collected gases from the space are ignited and are being used for the propulsion of the spacecraft [8].

The following figure (fig 4) shows the working of the air-breathing electric propulsion:

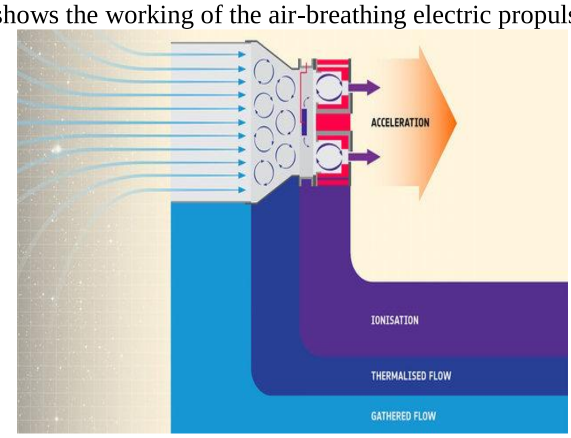

Fig 4. Air-breathing electric propulsion
Source: Adapted from [8]

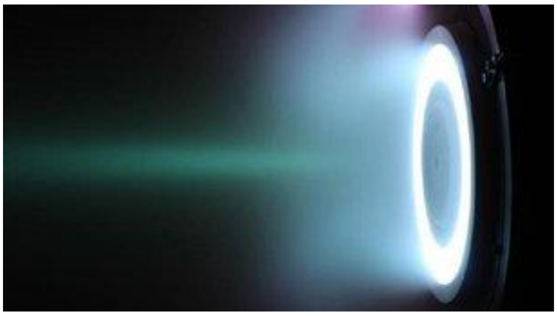

Fig 5. Thruster with Xenon Propellant
Source: Adapted from [8]

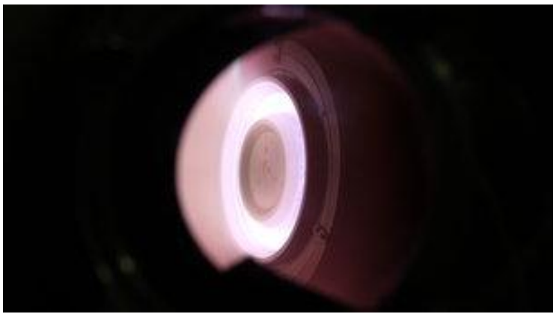

Fig 6. Thruster with Air Propellant
Source: Adapted from [8]

E. Combined Assembly of the Spacecraft:
The combined assembly of the technologies proposed from *A-D* can work as follow:

At the initial stages, the spacecraft will take-off from the runway like a normal aircraft by using the green fuel propulsion. By increasing the engine thrust with increasing altitude, the spacecraft will reach above the LEO. And as the earth atmosphere density begins to reduce and spacecraft reach at vacuum, the green fuel engine will switch to ion thruster.

A special gas trapping pump can be used to collect the gas molecules and this input is passed on to the ion thruster. The thruster work by collecting the gas molecules in the space and compress the gases to store it. Electric charge is applied to the gas molecules to accelerate them and produce thrust to push the spacecraft forward.

The deep space has very thin layers of gases, but there is a higher concentration of gases near the outer fringes of planets and other space bodies, so the spacecraft can hop near the planet's atmosphere and collect the gas molecules and produce thrust to travel a long distance in the space. This method can be very efficient for a deep space manned/ unmanned mission.

The space hopping of spacecraft for fuel collection and can open opportunities for space research.

V. CONCLUSION

Most of the spacecraft's design match with the previously proposed spacecraft AVATAR by DRDO but it was unmanned [9]. The composition of the four technologies (Aerospike engine Rocket spacecraft, green fuel, ion-thrusters and ABEP) with our proposed novelty can be a leap in future which can make the deep-space manned missions possible. The spacecraft technology can be very helpful for space body observation while traveling close to them and many atmospheric features of that space body can be revealed by these observations. Through the above mentioned four techniques, we can save the fuel of spacecraft at a large extent and can reduce its fuel consumption.

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