THE CONTEXT AND THE TECHNOLOGICAL CHALLENGES PROPULSION SYSTEM FOR MARS EXPLORATION AND BEYOND

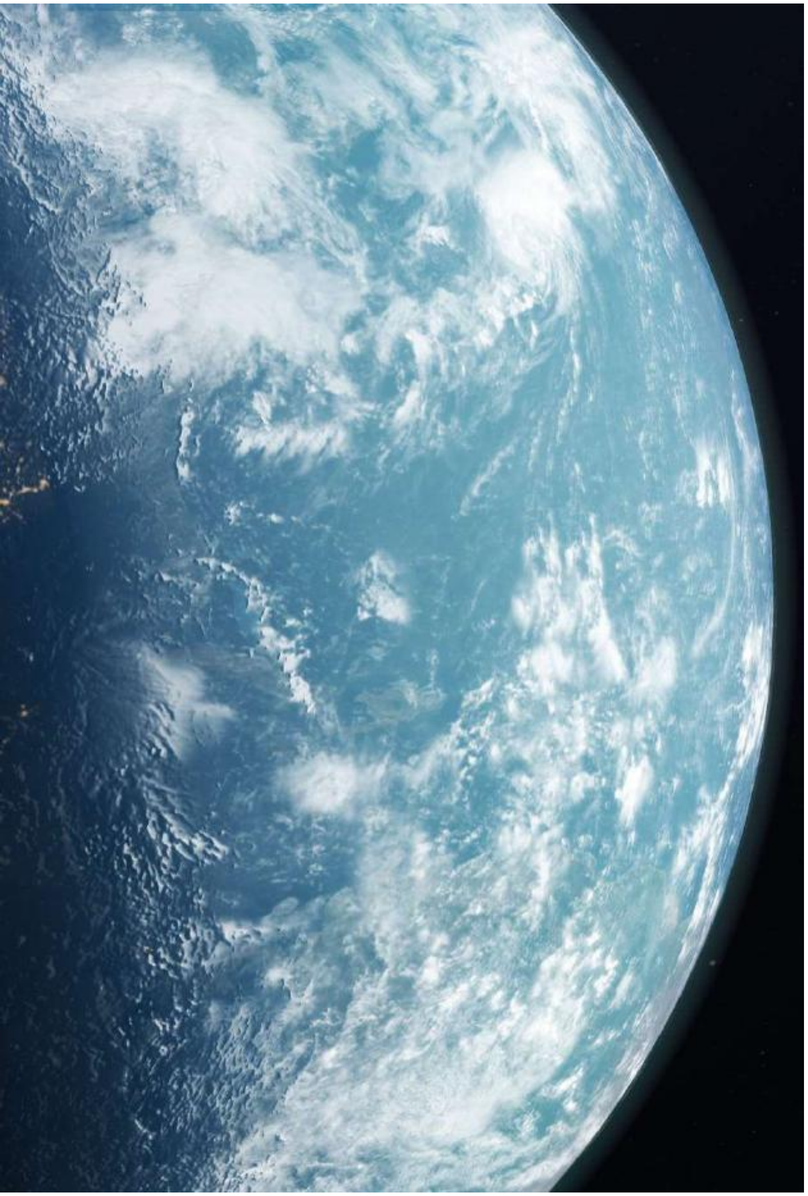
SAPIENZA
UNIVERSITÀ DI ROMA

GAUSS
Group of Astrodynamics for the Use of Space Systems

Sathish Kannan
Kathiravan Thangavel

OUTLINE

- INTRODUCTION
- CHALLENGES
- CLASSIFICATION
- CHEMICAL PROPULSION
- SELECTION CRITERIA
- PROPULSION ASSESMENT AND RESULTS
- CONLUSION



THE CONTEXT AND THE TECHNOLOGICAL CHALLENGES

- A real technological challenge “Time” and “Distance” as we move away from the Earth to explore our Solar System, and far beyond the Universe. It would be really pleasant, relaxing and advantageous to travel at the speed of light, perhaps driven by a black hole. But there are many contraindications.
- Today it is relatively easy to move from the Earth to the Moon with the current chemical propulsion.
- Mars requires about two years of round trip with the current propulsion.
- A shorter journey to reduce crew risks requires propulsion that is just currently available at the laboratory level.
- Pluto, the Heliosphere, the Kuiper belt reachable on a human time scale by using currently only imaginary propulsion systems.
- To date, the introduction of satellites into Earth orbit or on missions to Mercury, Venus, Mars, and Titan, etc. is conducted by using chemical propulsion.
- Going back to a more immediate perspective. The Mars mission planned by NASA for 2030 and using a super-heavy launcher and a 212-ton vehicle for a 6-manned crew is estimated to last, Earth-Mars cruise 6-9 months, Vicinity operations in Mars 30-90 days, Mars-Earth cruise 9-12 months.

PROPULSION SYSTEM TYPES

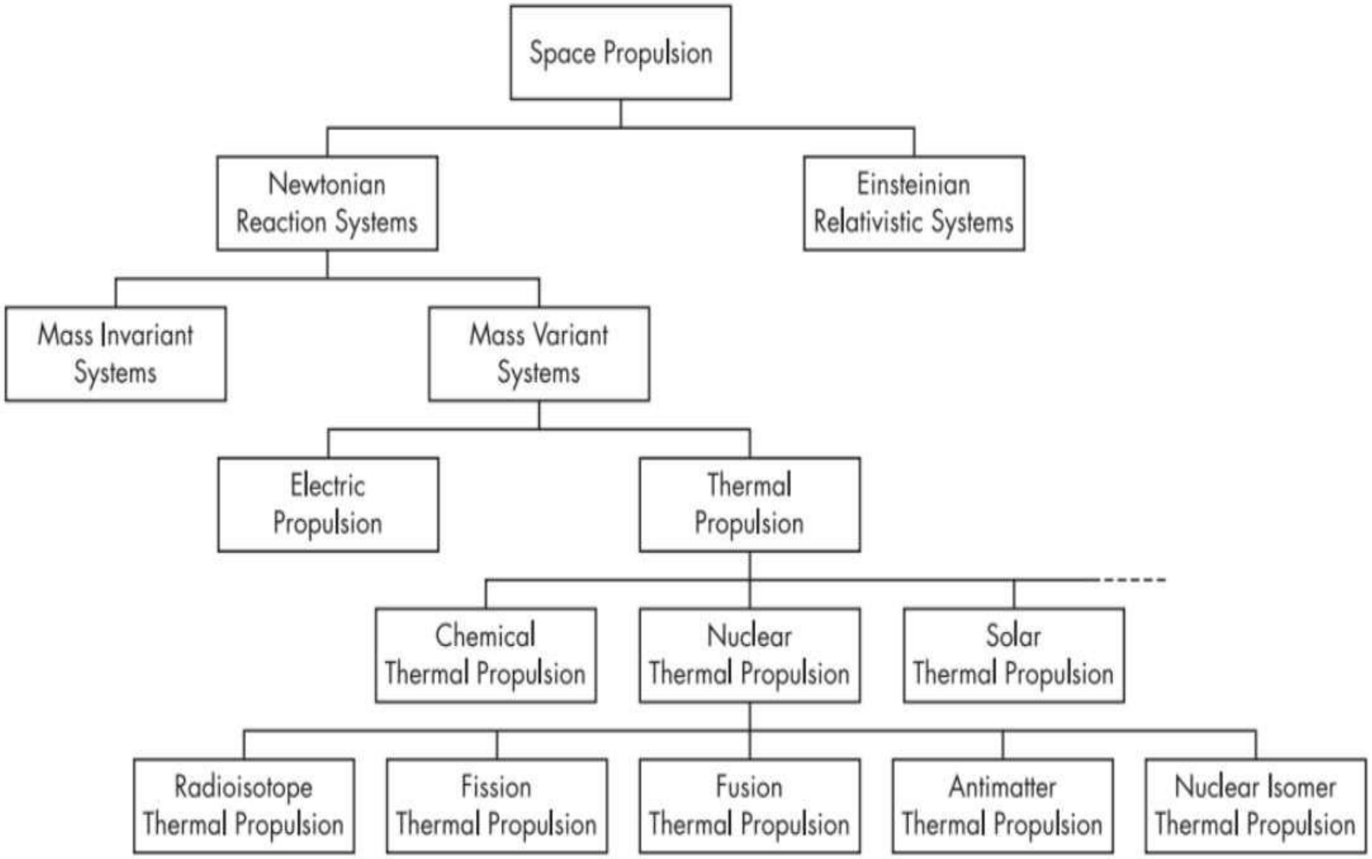


Figure 1. Classification of Space Propulsion[4].

FISSION-FUSION HYBRID CONCEPTS.

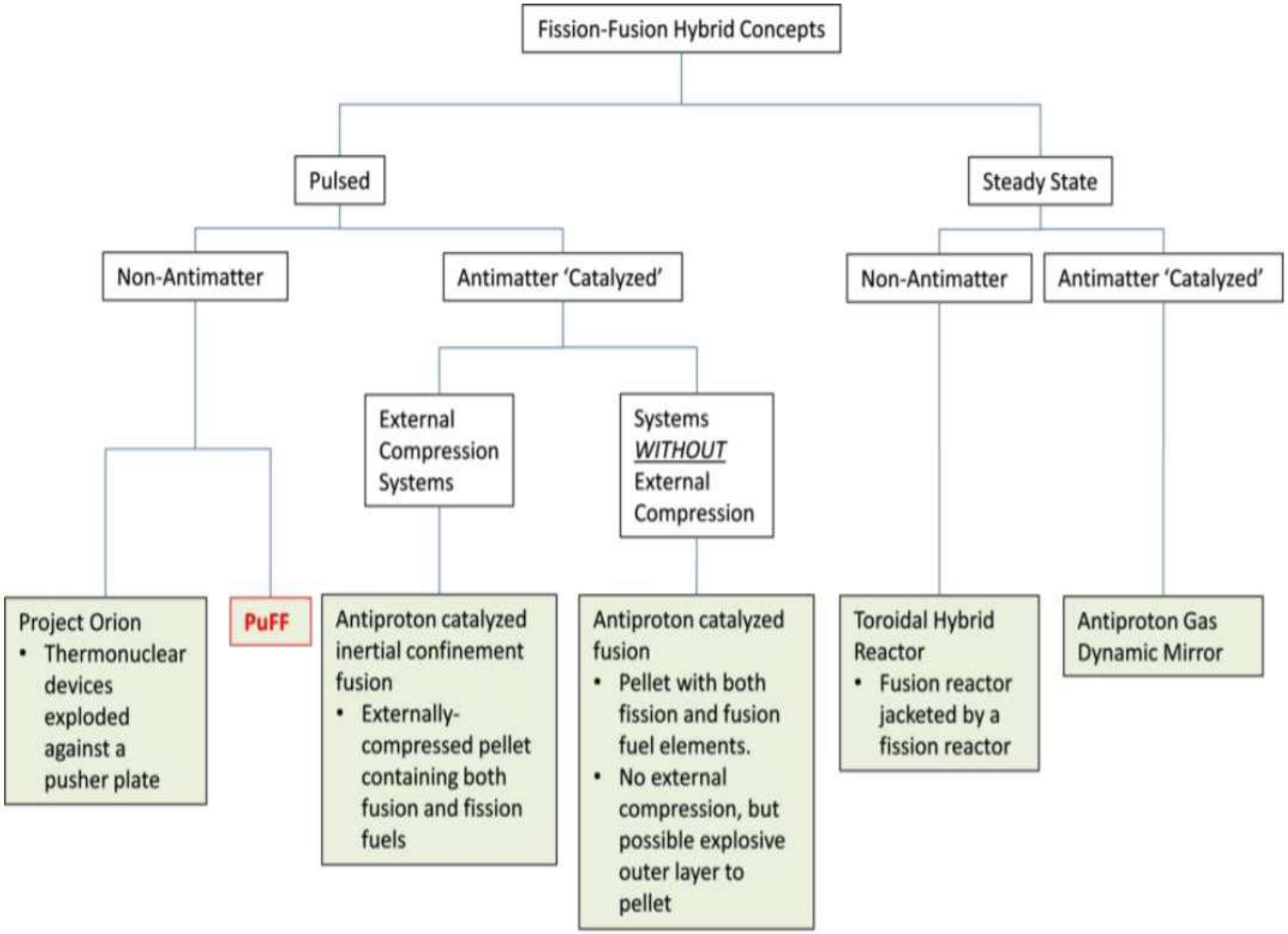


Figure 2. Fission-Fusion Hybrid Concepts[4].

CHEMICAL PROPULSION

CHEMICAL PROPULSION DEPENDS ON TAPPING THE ENERGY OF FORMATION OF CHEMICAL MOLECULES THROUGH A CHEMICAL REACTION BETWEEN FUEL AND OXIDIZER.

THE HIGHEST SPECIFIC IMPULSE FOR A CHEMICAL PROPELLANT EVER TESTED WAS 542 SECONDS WITH A TRI-PROPELLANT COMBINATION OF LITHIUM, FLUORINE, AND HYDROGEN.

HOWEVER, THE HIGHLY CORROSIVE NATURE OF FLUORINE MAKES IT VERY DIFFICULT TO HANDLE AND REDUCES THE LIFE OF PROPULSION SYSTEM COMPONENTS.

A COMMONLY USED PROPELLANT COMBINATION IS LIQUID HYDROGEN / LIQUID OXYGEN WHICH IS CAPABLE OF SPECIFIC IMPULSE 465 S (SUTTON AND SEIFERT, 1950). THIS SPECIFIC IMPULSE TRANSLATES INTO FLOW RATE OF M = 1KG / SEC IN A THRUST OF T = 465KG = 46.5N.

TIME CONSTRAINTS HUMAN SPACE TRAVEL BECAUSE IT DETERMINES EXPOSURE TO COSMIC BACKGROUND RADIATION (GAMMA RAYS, HEAVY CHARGED PARTICLES, ETC.)

THE BEST STRATEGY TO MITIGATE THE PROBLEM IS THE MINIMIZATION OF TRAVEL TIME.

FIRST CONCLUSION

Therefore, the first conclusion can be inferred as

- Restricting the time of interplanetary travel to the human scale requires a new propulsion technology capable of raising the specific impulse (The best I_{sp} from chemical reaction is about 465 sec) of at least a factor of two in order to minimize the weight of the spaceship,
- The higher speed, kinetic energy of discharge and the higher propulsive flow associated with the greater specific energy made available allow the delivery of higher power values.

Other considerations on space and time

- It is impossible to remedy from the Earth to problems that require the diagnosis of a malfunction and a corrective action.
- It is vital to go beyond performance from current engines

SELECTION CRITERIA

- Based on the above study, we are in need of alternative propulsion system which shorten the journey and a reusing capability.
- The propulsion system is selected based on the NASA, Technology Readiness Level (TRL) and other parameters such as Specific Impulse and Thrust.

TRL Level	Implications
1	Basic principles have been observed and reported.
2	Technology concepts and/or applications have been formulated.
3	Analytical/experimental proof-of-concept research has been performed.
4	Component and/or breadboard laboratory validation has been performed.
5	Component and/or breadboard validation tests in relevant environment have been performed.
6	System/subsystem prototype/model demonstration in a relevant environment has been performed.
7	System prototype function has been demonstrated in a space environment.
8	Completed system flight-qualified through ground/space demonstration.
9	Completed system flight-proven through successful space mission operations.

Table 1. NASA Technology Readiness Level[3]

Propulsion Technology	Specific Impulse (sec)	Thrust Capability (N)	TRL
Chemical Propulsion	465	2,000,000	9
Electric Propulsion (VASIMR)	30,000	80	5~6
Solar Thermal Propulsion	1000	4000	4~5
Nuclear Fission Thermal Propulsion	1000	100,000	5~6
Nuclear Pulse Propulsion	4000	260,000	2~3
Magneto-Inertial Confinement Fusion (MICF)	19,000	38,000	2~3
Direct Fusion Driven (DFD)	10,000	2,000	2~3
Pulsed Fission Fusion Propulsion	20,000	30,000	2~3
Antimatter catalyzed Fusion	500,000	26,000	2
Antimatter-matter Direct Particle Annihilation	30,000,000	1,200,000	1

Table 2. Propulsion Assessment Matrix[3]

PROPULSION ASSESMENT

- The Assessment matrix is prepared with Specific Impulse, Thrust, and TRL Level of the propulsion system technology.

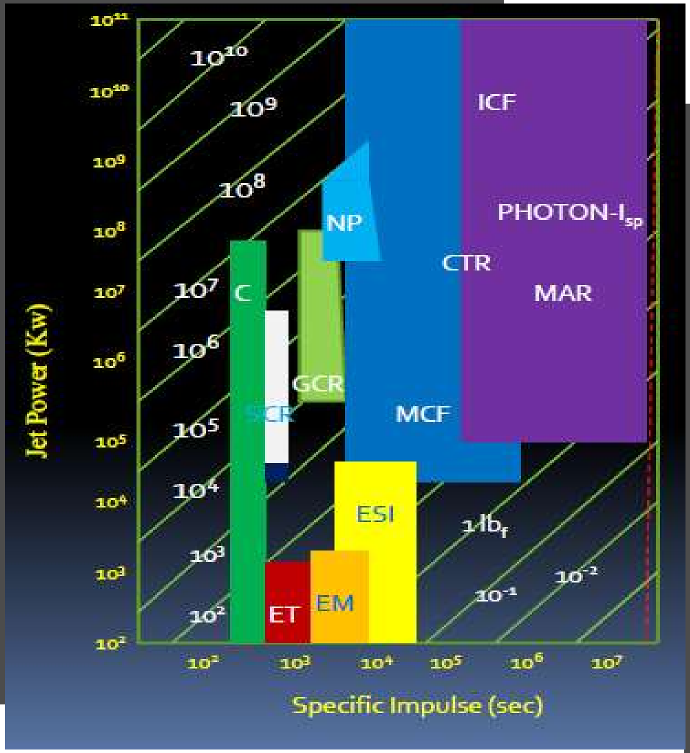


Figure 3. Propulsion Summary[2].

PROPULSION SUMMARY

- C-*Chemical*
- CTR-*Controlled Thermonuclear Reactions*
- ET-Electrothermal
- EM-Electromagnetic
- ESI-Electrostatic Ion Thruster
- GCR-Gas Core Reactor
- ICF-Inertial Confinement Fusion
- MCF-Magnetic Confinement Fusion
- MAR-Mass Annihilation Rocket
- NP-Nuclear Pulsed (Orion type)
- SCR-Solid Core Reactor

Results of propulsion assessment

The first screening was carried out based on the specific impulse of each technology since it was the primary criterion for meeting the mission requirements. The second level of screening was according to the TRL, in which a minimum of TRL of 2 was considered in order to realistically achieve the mission. The final screening process relies upon the legal implication, and effects on human performance. Salient points based on the trade analysis are the following:

Chemical propulsion (CP) has a specific impulse of 465sec and so has been screened out.

Antimatter-matter direct particle annihilation and Antimatter direct annihilation was ruled out due to its very low TRL, high shielding requirements against gamma-rays, and extremely high propellant cost with the existing schemes of production and storage of antimatter.

Nuclear based propulsion system technologies are removed due to its legal implication binding to Outer space treaty and other space laws.

The Electric Propulsion offers low mass and low-cost design due to their inherently high specific impulse. They did not fulfill the fast transit requirement of the mission due to their low thrust capability and were excluded.

Finally, solar thermal propulsion system is selected, owing to its advantage and reusability.

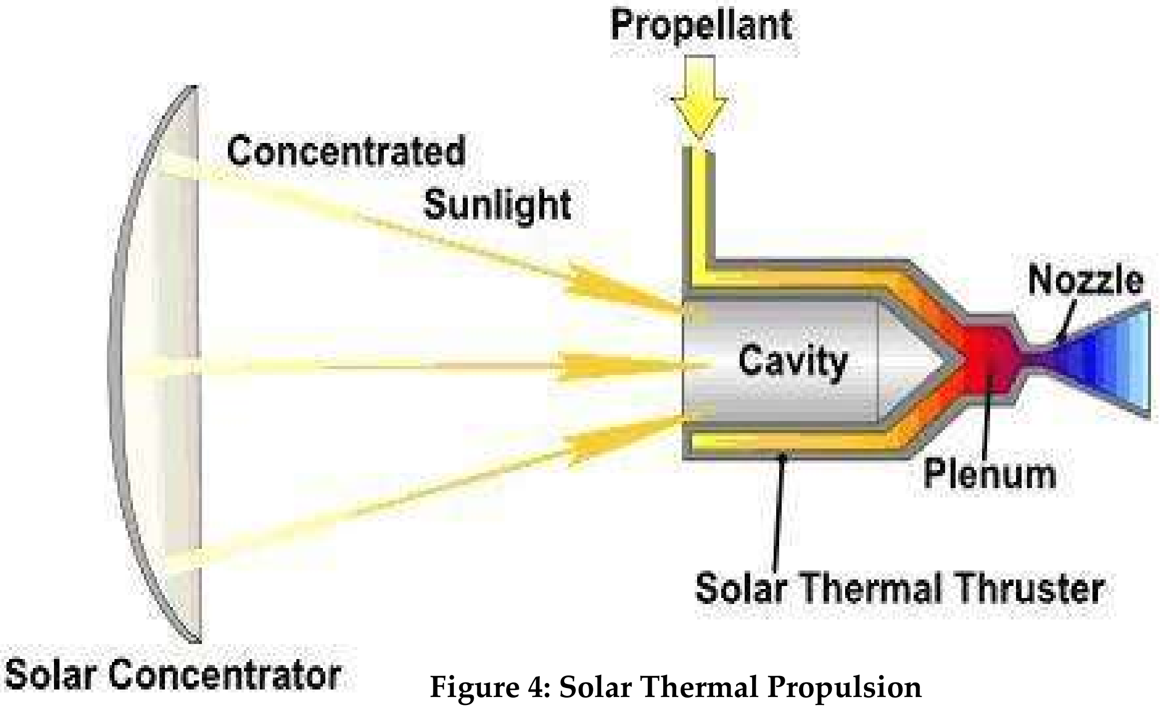


Figure 4: Solar Thermal Propulsion

Solar Thermal Propulsion

- A solar thermal rocket propulsion system uses solar power. The solar radiation from the sun is collected by concentrators and used to heat the propellant then the heated propellant is expanded through a nozzle to produce thrust. The engine thrust depends on the solar intensity and surface area of the collector.
- The main advantages of the solar thermal propulsion are a longer-life, lower-cost, more efficient use of the sun and more-flexible cryogenic launch vehicles and for on-orbit propellant depots.
- As the sunlight is being absorbed by a propellant and expanded through a nozzle, there are only two energy conversion steps: firstly, the sunlight is converted to heat, then heat energy is converted to kinetic energy. The fast-moving gas stream is expanded in the nozzle. The limiting factor for solar thermal rockets is how hot they can heat the propellant(Grey, 2006)

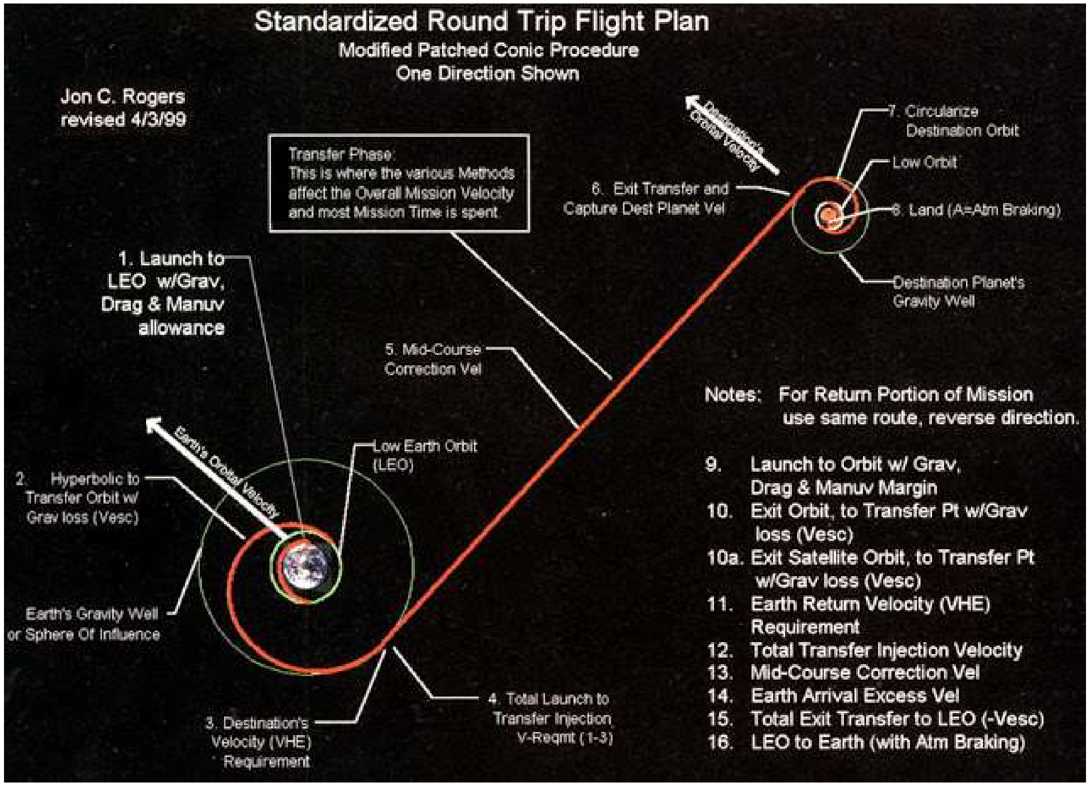


Figure 4: Earth to Destination.

- A chemical rocket such as SpaceX's BFR might achieve an Isp of 375s, which corresponds to an exhaust velocity of 3.67km/s. It would need a mass ratio of 5.13 to barely produce enough deltaV for a Mars mission.
- If the same mass ratio is granted for solar thermal rocket, it would have a deltaV of 19.6km/s. This allows for a Mars mission to be completed in under two months (10km/s departure, 9km/s insertion). It is also enough deltaV to reach Jupiter with a single stage.

The principal argument against solar thermal rockets, that their TWR is too low and their acceleration would take too long to justify the increase in Isp, can be beaten by using very high temperatures and very low mass sunlight collectors.

APPLICATION

Solar thermal propulsion could be applied in two particular areas: Earth-orbit transfer and scientific interplanetary missions.

1. Orbit Transfer Stage

The major application of commercial solar thermal propulsion is the orbital transfer of big communication satellites from low to geosynchronous Earth orbits. Multiple ignitions seem to be the most promising method for orbital transfer. This requires 11.5 tons of liquid hydrogen, producing a specific impulse of 750 s.

2. Interplanetary Spacecraft

Solar thermal propulsion systems can be used for interplanetary missions. In such missions, large arcs of solar concentrators are used to accurately focus sunlight onto the absorber. The heat is then transferred directly to the propellant, creating a continuous thrust to power the system. Such a method affords a higher efficiency of conversion of solar light to energy.

Comparisons have been made between conventional chemical propulsion and solar thermal propulsion. In the example of a Pluto flyby mission, it has been shown that a larger payload can be carried using solar thermal propulsion with the same amount of propellant. As such mission cost can be reduced.

CONCLUSION

- We selected propulsion technology that could potentially fulfill the mission requirements.
- Solar thermal propulsion is a promising rocket drive which has the potential to reduce commercial satellite launch costs and increase interplanetary mission performance.
- Nonetheless, key technologies need to be developed before operating systems can be developed.
- These include changes in the heat capacity of heat exchangers, lightweight and rigid structures, and the ability to store cryogenic hydrogen.
- The best use of solar thermal propulsion actually lies in commercial satellites and any future developments in this field are likely to rely on the cost of such propulsion. Thus space efficiency was traded for lower cost.
- Especially for the case of Mars colonization, we are in need of reusable propulsion system for the both way journey.
- The advantage of the proposed method is that it is relatively simple and approaches bipropellant propulsion efficiency.
- Other benefits include a vast reduction in the propellant-producing infrastructure needed to supply orbital refueling depots and the ability to land on Mercury.

Thank You for your Attention!

ANY QUESTIONS?

Contact:kannan.1873864@studenti.uniroma1.it

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