

A Theoretical Approach of UNIT (Unified Nuclear Integral Technology) Propulsion and its Potential for Future Applications in Space Exploration

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ABSTRACT

Space exploration is the present inevitable challenge for researchers. Various theoretical propulsion concepts have been evolved over the past years for space missions. Their potential remains as a key factor for the spacecraft to travel deeper into space in a shorter mission duration. The propulsion concept UNIT is an integrated nuclear propulsion technique that provides high entry, descent and landing (EDL) performance in such short duration to conquer other galaxies. This paper describes the theoretical approach of the UNIT propulsion system in detail. UNIT produces the highest energy possible by consuming nuclear fuel and possess the highest potential that opens new opportunities for space exploration. The principle is that the neutrons from the fusion are deliberately allowed to induce fission. It uses National Ignition Facility's laser beam for inertial confinement fusion followed by utilizing the power from tubular solid fuel cell. Thus, the net thrust is produced from the expansion of the combined plasma of the nuclear fusion and nuclear fission reactions through the nozzle.

KEYWORDS: Nuclear fusion, Nuclear fission, Nuclear propulsion, Space exploration, Inertial Confinement Fusion, Lawson criterion, Rayleigh Taylor instability

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I. INTRODUCTION

With the technologies available today, high amounts of energy could be produced only by nuclear reactions, either fission or fusion. Fission produces lower energy when compared to fusion[5]. Either breaking up of a heavy molecule called fission or combining the lighter molecules called fusion individually can provide energy many times greater than chemical propulsion systems[6]. The fusion process can be carried out only at extreme temperature of the order of 10^8 K, because only at these temperatures the nuclei can overcome coulombic repulsion which hinders the fusion of nuclei[1]. Also, generally, fission reaction occurs only when triggered by energized neutrons. The heavier nucleus which is stable initially is triggered by energized neutrons that make it unstable and thereby induce the fission reaction. Current propulsion techniques[5] that are under implementation in space missions have the potential of reducing the mission duration to other planets.

But they add more complexity to the mission including fuel quantity, duration and increased number of stages in accomplishing the mission. This is due to their low potential to produce larger thrust and low fuel to thrust ratio.

This paper deals with the combined performance of these nuclear processes in a single system in producing the highest energy and hence greatest thrust. In UNIT, nuclear fusion reaction is carried out at the main chamber and fission reaction at the sub-chamber. Fusion

reaction is initiated by the laser beam method[1] (Inertial Confinement fusion-ICF) and the fusion plasma is directed towards the main nozzle with the help of magnetic mirrors. Neutrons obtained as a byproduct along with the release of fusion energy is filtered from the fusion plasma and reflected back into the sub-chamber through the neutron port using super mirrors. Sub-chamber containing the uranium inside becomes unstable on accepting the neutron and fissions to produce stable fission fragments. The fission reaction is maintained subcritical to ensure that when fusion is shut down, fission is also stopped (correlative fission). UNIT thruster is designed preliminarily comprising the major components using Pro-E Wildfire since the practical development of the thruster is only possible with fundings and support from well-established research center (Design Overview). Super mirrors, Magnetic mirrors, ICF are commercially available technologies and are adapted in UNIT to increase the chances of its commercial development (Adaptation of existing technologies). Technology synergism illustrates the detailed working principle of UNIT thruster and the possible thrust is found to be greater than 10^{14} N. This thrust is double the thrust available from Nuclear fission propulsion and is much greater compared to chemical & electric propulsion[5].

Material to be used for the commercial development of UNIT thruster has to possess melting point greater than the temperature likely to prevail inside. The sub-chamber and sub-nozzle have to possess higher melting point than that of main chamber wall because it carries

fusion plasma on the outer side and fission plasma on the inner side. Similarly, main nozzle also requires the highest melting temperature as it expands the combined fusion and fission plasma through it. Hence, a double layered solid wall of graphite coated with starlite is preferred to meet the melting point requirements (Heat dissipation and other Challenges). The potential of UNIT thruster is analyzed theoretically for possible thrust neglecting the losses of energy of neutrons (Energy Calculation). Results showed that UNIT possess highest thrust to fuel weight ratio. UNIT possess the advantage of carrying low fuel weight. UNIT also shortens the mission duration because of its highest thrust compared to other propulsion systems which is shown in table and graph (Fig.3).

II. INERTIAL CONFINEMENT FUSION

The UNIT propulsion system consists of two chambers which act as a fusion reactor (main chamber) for neutronic fusion and a fission reactor (sub-chamber) for binary fission, respectively. Neutronic fusion is achieved by the Inertial Confinement Fusion (ICF) method[1]. In general ICF initiates the fusion reaction by heating and compressing the fuel capsule in a pellet form[1]. To compress and heat the fuel, energy is delivered to the outer layer of the capsule either with the help of high energy laser beams, or electrons or ions. When the laser beams are focused on the capsule, due to some imperfections on capsule there are possibilities of non-uniform heating and Rayleigh Taylor instabilities[4] to occur. Hence, fuel capsule is placed inside a hollow area which converts the laser beam into X-rays resulting in uniform heating of the capsule. For confinement fusions, sufficient density and confinement time are required as specified by Lawson criterion[1]. In ICF, the confinement times are extremely short (10^{-10} s) and the particle densities are greater than 10^{25} cm³. This solves the demand of our UNIT propulsion system which is focused on shorter confinement time that in turn proliferates the plasma production. Thus, UNIT induces fusion in its chamber, which contains a capsule filled with fusion fuel, by ICF.

III. CORRELATIVE FISSION

Nuclear fission is a man-made deliberately-produced nuclear reaction, achieved with the help of neutrons and hence UNIT also follows the same methodology for inducing fission reaction in the fuel atoms filled in a portion of the sub-chamber. Here the neutrons from the fusion are utilized to induce the fission reaction and thus, both the fusion and fission in UNIT are correlative. The sub-chamber containing the nuclear fission fuel, when induced by neutrons, releases large amount of energy along with the release of free neutrons and gamma rays. Fission reaction continues as a chain reaction if the byproduct free neutrons are not absorbed. It is because of the free neutrons moving in random directions have a mighty chance of inducing fission in other fuel atoms. This in turn leads to an uncontrolled chain reaction[8] producing multiple neutrons in increasing order leading for infinite fission stages. UNIT illustrates the reason for its fusion-fission correlation by the chain reaction. Shut down and uncontrollability of the fission reaction can be controlled with this correlative approach along with the use of Carbon control rods.

IV. DESIGN OVERVIEW

The unit propulsion has two chambers, a main chamber and the sub-chamber. Fusion is carried out in the main chamber and fission in the sub-chamber. Neutrons from fusion are deliberately allowed to induce fission in the sub-chamber. They are filtered and reflected into the sub-chamber by super mirrors. Control rods absorb the free neutrons from the fission. Both fusion and fission plasma are directed with the help of magnetic mirrors and reflectors. Combined hot plasma is expanded through the nozzle to produce thrust (Fig. 1).

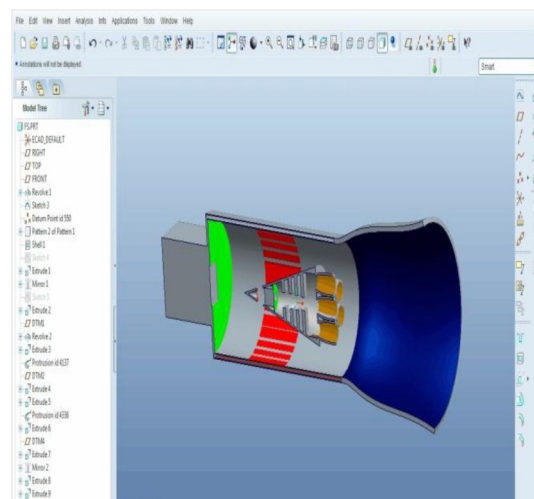


Fig. 1. Front rectangular portion of the main chamber - ICF setup; Front portion of the subchamber - Uranium; Green - magnetic mirror; Golden - sub-nozzle; Red - Super mirrors; Gap between conical sections - Neutron port.

V. ADAPTATION OF EXISTING TECHNOLOGIES

For the choice of driver and fuel for fusion and reactions, UNIT adapts with currently existing technologies so that complexity of the system is reduced. For ICF which occurs at the main chamber, UNIT prefers laser driver to initiate fusion by exciting the fuel to high plasma temperature of about 10^8 K.

UNIT prefers deuterium and tritium as fuel mixture to be filled in the capsule of the ICF operational setup. This is the easiest method of producing fusion which also releases an enormous amount of energy among neutronic fusions. Currently, the largest operating laser is the Omega laser[1] which consists of 60 Nd-glass (neodymium ions embedded in a matrix of yttrium aluminum garnet $Y_3Al_5O_{12}$ crystal or glass) laser beams delivering a total energy of 40 kilojoules is utilized in the UNIT propulsion, since it is capable of releasing high power in a short time. The laser setup is designed for meeting the energy needed with as minimum dimensional parameters as possible. Nd-YAG laser which is a gas laser have been preferred to solid laser for its high directionality and highly monochromatic characteristics.

Fission of a heavy nucleus needs high input energy to overcome the force which holds them into a definite spherical shape. Uranium-235 is the fission fuel being used in the UNIT system for the reason that it is fissionable with neutrons of about 2MeV. Thus, energy loss in neutrons from the fusion would have no effect on the fission reaction