Human Interplanetary/Asteroid Vehicle Concept

William C Strobl[1]
Retired General Dynamics Vice President and
Program Director of Advanced Launch Systems
Carlsbad, CA 92009

Richard Hora [2] and James Mildice [3]
Earth Space Applications, Inc.
San Diego, CA 92074

Abstract

At Space 2010 Conference we presented a technical paper identifying many advantages of nuclear electric propulsion over nuclear thermal (NERVA) to transfer humans to Mars and the Asteroids. The primary benefits were much shorter transfer times for a Mars or asteroid mission, vehicle reusability, no nuclear space debris (vehicle flies to Sun at end of life), and a lighter total system weight.

At Space 2011 we presented a technical paper that illustrated methods to significantly reduce the size of the radiator for a nuclear electric propulsion system. We illustrated that by designing the Brayton Cycle electric power generating system off optimum weight by about 15%, and improve the turbine inlet temperature to about 1500 K, would increase the total system weight by only about 7 % but allow a reduction in the radiator size by a factor of 5/1. Increasing the turbine inlet temperature to 2000 K increases the system weight by5 % but reduces the radiator size by 14/1. We traded a small net weight increase to ease an operational assembly requirement.

This technical paper will present a concept nuclear electric vehicle system design that incorporates the data from the above papers and other features that will satisfy other operational requirements. Features presented will provide increased mission success and be friendlier to the Astronauts. Such features as modules for ease of assembly and disassembly, module placements to ease change/repair of propellant tanks and thrusters (within a safe nuclear radiation environment), module/element redundancies and without module fluid interfaces. We will also provide examples for the common use of system elements for other space applications.

I. Introduction

NASA is intensely defining/evaluating “Human Rating” requirements to be applied to potential existing and new launch vehicles. Retro fitting is more difficult than including a requirement in the initial design. For example, prior rocket vehicle history failures seem to occur early in flight so adding an escape tower for the early part of the flight significantly improves the system reliability. This is one approach that applies to existing and new designs.

For human lunar, interplanetary and asteroid missions we must provide more attention to astronaut safety and survivability for a vehicle that is millions of miles from earth. We must expand the requirements of the design to allow the astronauts a significant number of options to implement, first to survive then to complete the mission successfully and safely. These requirements must be well thought out and implemented in the initial system design.

The authors are uniquely qualified to discuss these subjects. Bill Strobl and Jim Mildice each have more than 50 years experience in all aspects of launch and space vehicles design, analysis, safety, reliability, cost, and application. In a 1999 NASA funded study there was a requirement for one loss of crew in 10,000 flights. Bill and Jim presented a design that had a capability of 1 loss of crew in 19,000 flights.

During the NASA contract funded “Manned Planetary” studies from 1962 into 1965, managed by Krafft Ehricke at Convair, Bill Strobl defined the vehicle systems presented in the published reports. He spent nearly 4 years integrating nuclear thermal, NERVA and Phoebus, engines into vehicle systems. The final project study report recommended the nuclear thermal engines until a nuclear electric system became available.

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[1] Retired, 2906 Via Pepita, Carlsbad, CA., AIAA Senior Member
[2] Vice President – Business Development, PO Box 224, Poway, CA 92074, AIAA Member
[3] CEO, PO Box 224, Poway, CA 92074, AIAA Senior Member

II. Discussion

Minimum weight vehicle designs to transport humans to visit Mars or Asteroids seem to be a desired goal. We need an approach that provides every possible means to allow the astronauts first to survive and then complete a successful mission. The astronauts must have options available to them to "jury-rig" a "field" solution to any problem even if it is to wait for a recovery vehicle. This paper will provide an initial list of many survivability/safety/operational requirements and the weight impact to implement them into the vehicle. We will present a nuclear electric propelled vehicle system that can absorb the enhancement requirements and still deliver a 230 - day (100 – 30 – 100) trip timeline. The vehicle concept should be considered as a "Point of Departure Design" for a major all encompassing space architecture study. Any new human transport space vehicle will effect the selection of the vehicles required to deliver them to Earth, Lunar, L-1 and other orbits.

From Our system studies and prior technical papers, we concluded that a vehicle system with a 15MWe electric generating power system would support a 230 day (100–23-100) round trip human mission to Mars. The electric power-generating module would consist of the items presented in Table 1.0 Electric Power Module Elements. The system also contains those items considered standard like redundant avionics, 1.4 or higher safety design factor. Then adding a crew module and a propulsion module represents our baseline

Table 1.0 Electric Power Module Elements

5 Year Life Pebble Based Reactor
100 Meter Nuclear Safe Distance Shield
Regenerator
Dual Compressor & Turbine
AC Alternator
Power Management and Distribution
Heat Pipe Main Radiator
General Lines & Ducts
System Structure
Turbine Inlet Temperature 1800 K

nuclear electric powered space exploring system as illustrated in Figure 1.0. The electric power module dual sided heat pipe radiator is 1200 square meters (2400 square meters radiating surface). The propulsion module assumes (4) 5MWe engines (one reserve) and a cluster of propellant tanks. The basic space exploration vehicle, as shown, weights are presented in Table **2.0**

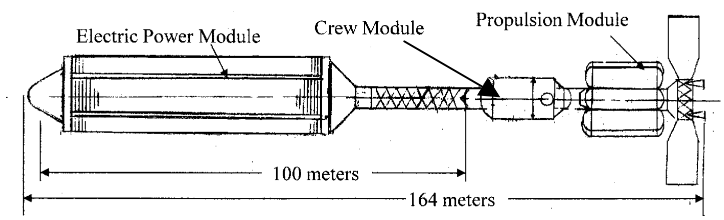

Figure 1.0 Baseline Human Space Exploration Vehicle

Table 2.0 Baseline Human Space Exploring Vehicle Weights

System	**Weight (kg)**
Electric Power Module	**47,900**
Crew Module	**29,500**
Propulsion Module	**38,000**
Propellant	**59,700**
Grand Total	**175,100**

To this baseline design concept we will add safety and survivability enhancements in two steps. First enhancements will be those applicable to the crew module and second to the power and propulsion modules. Table 2.0 describes a list of enhancements that would provide the astronauts a healthier and safer trip as well as many options to support their survivability and complete the mission.

Table 3.0 Astronaut Survivability/Safety Enhancements

Shortest Mission Travel Time
Solar Flare Protection
Artificial Gravity
Expand Engine Radiation Safe Area
Astronaut Ability For In-flight Repair
No Fluid Connections Across Docking Interfaces
Apply Interchangeable Multiple Power Modules
Add Provisions for Longer Trips
Independent Maneuvering Propulsion
Identical Power Modules for Crew & Cargo Vehicles

We plan a 230-day Mars mission but include provisions for a 302-day mission. Thus, if the astronauts had a problem to leave Mars and tried every fix possible without success, they would have provisions for 172 days and could wait for a second vehicle to arrive at Mars and save them. Solar flare protection and artificial gravity will provide a healthier environment for the astronauts. Expanding the engine radiation safe area will allow astronauts to do in-flight repairs. The vehicle system illustrated in Figure 2.0 also includes a small maneuvering capability to allow changing the propulsion and or the electric power module to ease initial assembly or switching either with a cargo vehicle at Mars.

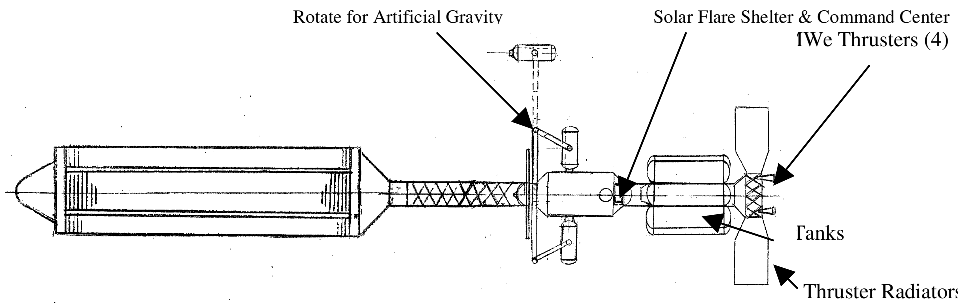

Figure 2.0 Space Exploring Vehicle with Astronaut Enhancements

Table 4.0 Weights FOR space Vehicle with Astronaut Enhancements

System	Weight (kg)
Electric Power Module	47,900
Crew Module Weight	46,200
Propulsion Module	40,200
Propellant	80,700
Total	215,000

We selected a Brayton Cycle with a regenerator for the baseline vehicle, but before the next step of adding enhancements to the propulsion and electric power modules we need to re-look at the Brayton Cycle as to the use of a regenerator. The basic Brayton Cycle has a larger radiator and reactor than one with a regenerator but a much lighter weight. Part of the approach to reduce radiator size (as discussed in detail in our Space 2011 paper) is to raise the radiator exit temperature, which reduces the size of the radiator but increases the flow rate and the size of all the other elements. In plotting the data the radiator size and weight decrease faster than all other elements increase until the reverse occurs. Since we begin with larger/heaver radiator and reactor without the regenerator, the radiator does become smaller but not as small as that of Brayton cycle with a regenerator. The reactor becomes larger than the case with a regenerator. If we pursue multiple electric power modules to increase the options for the astronauts to survive and complete the mission may change the selection.

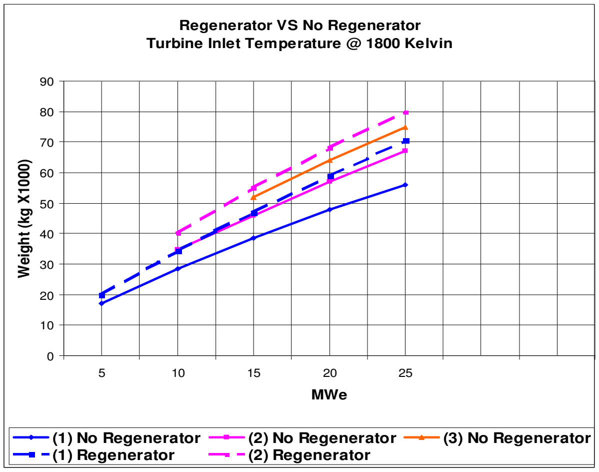

Figure 3.0 Electric Power System Single or Multiple Module(s)

Figure 3.0 plots electric power system weights for single and multiple modules with or without a regenerator. A 15MWe system without a regenerator weighs about 9000 kg less than a system with a regenerator. However, two 7.5MWe systems without a regenerator have the same weight as a single 15MWe module with a regenerator. Three 5MWe systems without a regenerator are only 4,000kg heavier. Two or Three electric power modules would provide another option for the astronauts to survive. Each module has two turbines and two compressors. If the astronauts are ready to leave Mars and for the two-module case, if the reactor has to be shut down in one of the modules, and the second module would have access to that radiator, it could run more efficiently and produce a total of 11.8MWe power. In a similar situation for the three-module case, the two remaining modules could produce 12.5MWe. Either one of the cases would allow the astronauts to return safely but take longer.

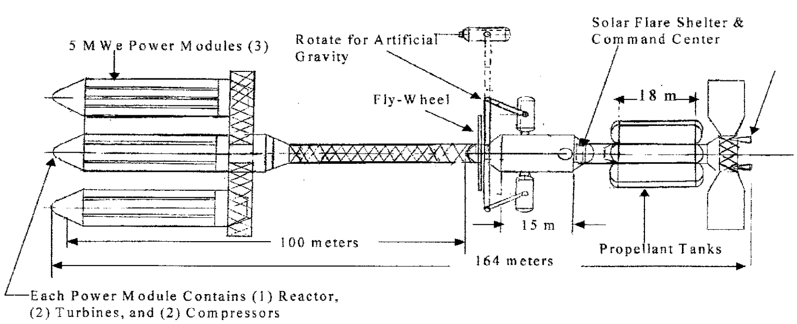

Figure 4.0 Space Exploration Vehicle with Enhancements

Selecting multiple modules will require shielding the sides of the reactor. For single 5MWe reactor and applying a 20 degree half cone, the shield weight required at the top of the reactor is 1324 kg. Removing the shield mass outside the reactor diameter and using that weight, with the same thickness as on top, covered about one third the reactor cylinder. Adding shield to the remainder of the cylinder raised the weight to 2850 kg (selected) and full coverage at 3550 kg.

Table 5.0 Weights for Space Exploration Vehicle with Enhancements

System	Weight (kg)
Electric Power Module	56,900
Crew Module Weight	46,200
Propulsion Module	47,000
Propellant	111,613
Total	261,800

Table 6.0 summarizes the weights of the three cases presented herein. Of interest to note that the propellant change between the last two cases compared to that between the first two cases. The Mars mission has a fixed time to satisfy with a propulsion system with a large spread of specific impulse value. For a given weight of a vehicle system, the specific impulse has to be properly balanced to satisfy the time constraint and minimize propellant required. The electric power available defines the thrust for a given specific impulse. Applying the same electric power in all three cases allows use of a better specific impulse to thrust ratio for each case.

Table 6.0 Summary

	Enhancements		
	Basic	**Crew**	**All**
Shortest Mission Travel Time	Yes	Yes	Yes
Solar Flare Protection	No	Yes	Yes
Artificial Gravity	No	Yes	Yes
Expand Engine Radiation Safe Area	No	No	Yes
Astronaut Ability For In-flight Repair	Yes	Yes	Yes
No Fluid Connections Across Docking Interfaces	Yes	Yes	Yes
Apply Interchangeable Multiple Power Modules	No	No	Yes
Add Provisions for Longer Trips	No	Yes	Yes
Independent Maneuvering Propulsion	No	Yes	Yes
Identical Power Modules for Crew & Cargo Vehicles	No	Yes	Yes
Crew Vehicle Total Dry Weight (kg x 1000)	**115.4**	**134.3**	**150.1**
Crew Vehicle Propellant	**59.7**	**80.7**	**111.6**
Total Crew Vehicle Weight	**175.1**	**215.0**	**261.7**

In conclusion, a 15MWe power system with all the Survivability/Safety Enhancements identified easily supports a 100-30-100=230Day Mission to Mars.

Our recommendations to NASA are:

1. Conduct a major architecture study that includes both nuclear thermal and nuclear electric systems. Include the approach defined in all three of our papers. Fund industry to conduct the studies and have a member of every NASA center on the management team. Thus every center will have an input to the final decision.
2. Convert the enhancements identified in this paper to "hard" requirements.

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