AIAA SPACE 2013 Conference and Exposition
September 10-12, 2013, San Diego, CA

AIAA 2013-5380

Near Earth Asteroid (NEA) as an Alternative Manned Interplanetary Spaceship

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Near Earth Asteroids (NEAs) are considered to be our next destination for manned deep space exploration even before human-rated Mars mission as President Obama has addressed to send human to NEAs by 2020. NEAs are promised small bodies in solad system with abundant resource (e.g. water ice, volatile, etc.) that can be utilized for future human spaceflight propulsion fuel, science research purposes, and commercial mining activities and so on. On the other hand, radiation shielding, life support capability and other critical issues for human interplanetary spaceflight to Mars and beyond are still remained unsolved. This paper suggests transforming asteroid into manned interplanetary spaceship to explore Mars, Jovian system and beyond with utilizing applicable resources (e.g. water ice, ore, volatile, etc.) on board for semidirect human interplanetary mission and its comparison to conventional stopover interplanetary exploration methodology. This Manned Asteroid Interplanetary Spaceship (MAIS) concept has advantages as follows: (a) Transforming asteroid into a spaceship gives better understanding to asteroid composition and physical parameters for forming an effective asteroid deflection strategy, (b) Water ice, ore and volatile resource may be utilized for life support and propulsion solutions, (c) Utilization of asteroid regolith and ore are porposed for radiation shielding countermeasure, (d) This concept may increase our knowledge on extraterrestrial colonization on small bodies in solar system. (e) Planetary defense correlation: unmanned MAIS with remained propusion system on board is an useful method to deflect an Earth-threatening asteroid by remote control after mission has ended.

Nomenclature

MAIS	=	Manned Asteroid Interplanetary Spaceship
NEA	=	Near Earth Asteroid
NEO	=	Near Earth Object
AU	=	Astronomical Unit
ISRU	=	In-Situ Resource Utilization
ΔV	=	Change in velocity
Orion MPCV	=	Orion Multi-Purpose Crew Vehicle
r	=	Radius from the center of rotation
Angular Velocity	=	Spin rate
Tangential Velocity	=	Rim speed of contact floor
Centripetal Acceleration	=	Artificial gravity level

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I. Introduction

HUMAN interplanetary spaceflight faces critical issues from life support, radiation shielding to propulsion fuel shortage and resupply, and bone weight loss risks. Spaceship that is capable to carry out such long term spaceflight is considered to be consisted of radiation protection shield, meanwhile with highly sufficient regenerative life support systems and powerful propulsion capability to shorten total trip is still remained uncertain of how to achieve this complex task. This paper suggests an alternative option for human deep spaceflight to explore worlds such as Mars to Jovian system and even Titan the Saturnian moon, by transforming Near Earth Asteroid (NEA) out of Near Earth Objects (NEOs) and utilizing resource (e.g. water ice, volatile, etc.) on board for sustaining crew memebers' life support and deal with radiation shielding countermeasure and other issues. This Manned Asteroid Interplanetary Spaceship (MAIS) concept is proposed to perform semidirect interplanetary spaceflight to Jupiter and Saturn. Fruthermore, comparisons of MAIS to conventional stopover interplanetary spaceflight concept is made to investigate foreseeable advantages and issues from either aspects.

Near Earth Asteroids or NEAs from Near Earth Objects (NEOs), are asteroids, ceased comet neucleus or other rocks in Earth's neighborhood by gravitational attraction and circle around Earth-Moon system in different speed, inclination rates[1]. Some NEAs with Earth-like orbit have less velocity that relative to Earth, are highly considered as possible destinations for human deep space exploration due to their lower ΔV for spaceship to access easier (as shown in Figure 1. and Figure 2.).

Compositions of Near Earth Asteroids are identical to those from main asteroid belt. Many of them are rocks of which water ice embedded with dust particles; in larger NEAs are believed to have regolith. Volatile such as hydrogen, nitrogen, carbon dioxide, are sealed within asteroid's ore. Proportion of volatile is much higher in some comets' remnants or neucleus[2].

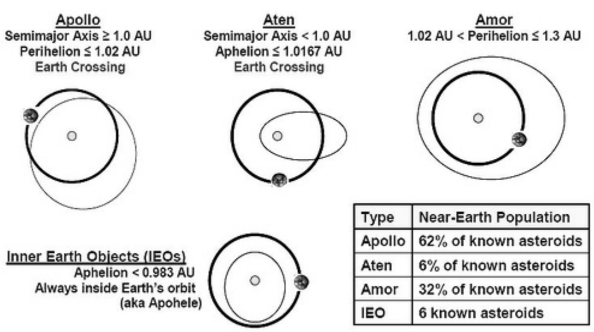

Figure 1. *Near Earth Asteroid families shows different orbit elements. (Source: NASA NEO program)*

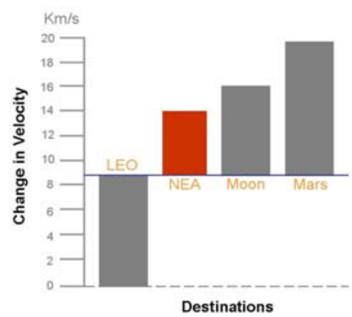

Figure 2. *ΔV requirements comparison by destinations shows getting to NEA needs much less energy than those needed for Moon or Mars.*

II. Concept of transforming NEA into manned interplanetary spaceship

As President Obama has addressed in 2010 to send human to Near Earth Asteroid and back by 2020, NEAs have been set for our next destination since then. Still, it encounters old problems that we found ourselves are incapable of sailing to open seas with stars. For years, human-rated interplanetary spaceflight to Near Earth Asteroids, Mars or beyond has been discussed. These include our continuous effort on development of advanced regenerative life support system, water recovery devices, radiation protection countermeasures, etc[3].

This paper, however, proposed "Manned Asteroid Interplanetary Spaceship" concept and analyze the possibility of transforming NEA itself into interplanetary spaceship for future human deep space exploration by utilizing resource (water ice, volatile, and valuable ore) to produce necessary substance for expedition crew members through ISRU (In-Situ Resource Utilization) method along the journey during deep space exploration[4]. Image as shown in Figure. 3.

Main component of MAIS is presumed to be consisted of Orion MPCV (Multi-Purpose Crew Vehicle) as a central element, with new designed Inflatable Habitat Module and other cargo, probe carriers, propulsion system or pellet engine which is proposed here to accomplish a standard MAIS.

Because of MAIS concept is to convert asteroid into movable object to travel around the solar system, main idea is to provide alternative solutions and possibilities for certain issues of human interplanetary spaceflight and to correlate with planetary defense from Earth-threatening asteroids as follows:

A. Life Support and ISRU Issue

Carrying water and food on human interplanetary spaceship may not be a good idea. Monthly water and oxygen quantity on ISS to support minimum 4 crew members exceeds 6,000kg and approximately 72kg for food totally. For a mission to fly by Mars, Jupiter and beyond, hundreds of tons of substance and material are needed. This could weigh the spaceship in impractible scale and is difficult to be resupplied.

MAIS concept utilizes resource on selected asteroid from ore, water ice, and volatile inside it to produce drinkable water, oxygen for breathe and mineral substance for on board plant growing facility to cover up to 6 crew members to live during the expedition.

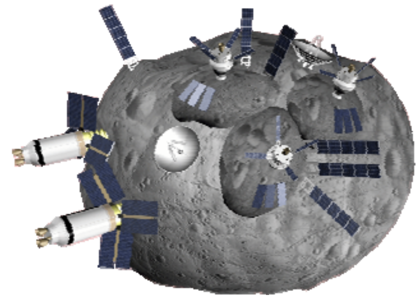

Figure 3. *Image of MAIS concept.*

C-type NEA is recommended for building MAIS due to it has up to 10% of water content, smaller density for easier ore excavating process and mass for propulsion needs. Table 1. shows minimum size of asteroid selection for producing water and oxygen in different mission scales. Note that the numbers calculated are based on only when ISRU system conversion efficiency is 100%. Also, Figure 4. shows a scheme of whole system on board MAIS.

Mission Classification	Asteroid Type	Mission Duration (months for round trip only)	Minimum Asteroid Size for H_2O & O_2 production requirement
Mars Class	C-Type (Density: 1.3~1.6 g/cm³)	16 (minimum)	Diameter: 11.27m Mass: 975.360 MT
Jupiter Class	C-Type (Density: 1.3~1.6 g/cm³)	144 (minimum)	Diameter: 23.45m Mass: 8,778.24 MT
Saturn Class	C-Type (Density: 1.3~1.6 g/cm³)	168 (minimum)	Diameter: 24.69m Mass: 10,241.28 MT

* Calculation for size of asteroid is base on 100% ISRU efficiency from ore material into water and air products.

Table 1. *Minimum requirement for asteroid selection .*

B. Radiation Shielding Issue

Regolith on larger asteroid may be used for radiation shielding countermeasure[5]. Thickness of lunar regolith radiation shielding suggested by researchers (Nealy, John E. et al) indicates that under active solar flare event need to be exceeded 50cm to 100cm to meet dosage requirements. MAIS uses regolith for radiation shielding also reduces preassembled material from Earth and cost[6].

C. Space Colonization Issue

Building MAIS is a partial process of space colonization. This concept will enhance our knowledge on building a living space and to develop a sequence of resource process methodologies on small bodies in the solar system.

D. Planetary Defense Issue

After interplanetary exploration ends, crew members use Orion Reentry Module to back to Earth, unmanned MAIS is set course to return to NEA region. In case of an Earth-threatening asteroid is discovered, unmanned MAIS is able to be remote controlled to fire propulsion engines to adjest its way to intercept and deflect the hazardous asteroid.

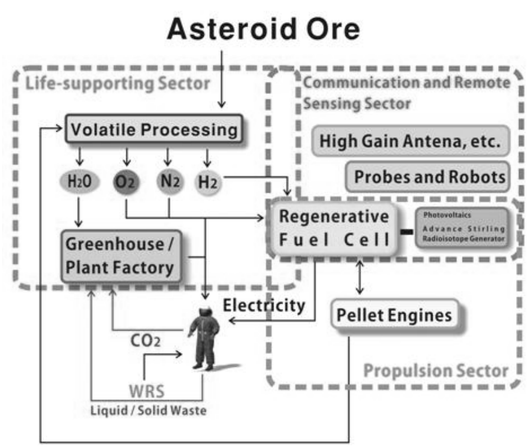

Figure 4. *Schematic view of system integration on board MAIS.*

E. Artificial Gravity Issue

In order to prevent expedition crew members from suffering to bone weight loss during long term deep space mission, artificial gravity on spaceship which is designed for human-rated interplanetary exploration by using centrifigual force is widely suggested. However, spaceship with centrifigual force or artificial gravity system would increase the total mass, construction cost and system complexity; MAIS concept proposes using asteroid rotation directly and modify the rotation rate (Rotation Per Minute, rpm) if needed for artificial gravity purpose.

Comfort zone for artificial gravity was researched and was suggested from 0.3g to 0.7g (Hill & Schnitzer, Gilruth et al) [7-8]. Radius and parameters for artificial gravity are shown in Figure 5., Figure 6., and Figure 7.. Minimum size for asteroid selection in Table 1. showed candidate asteroid for building MAIS may exceed radius from the center of rotation needed for generating

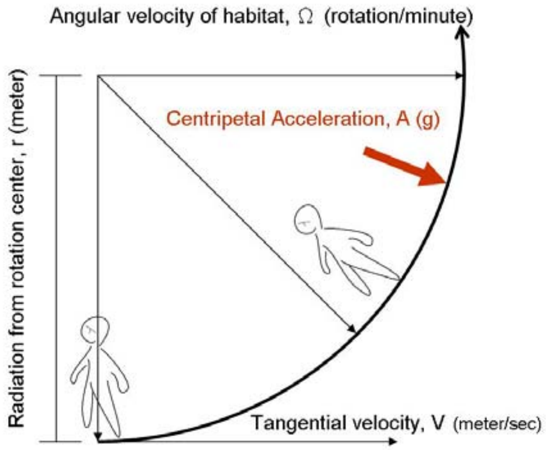

Figure 5. *Elements of artificial gravity calculation.*

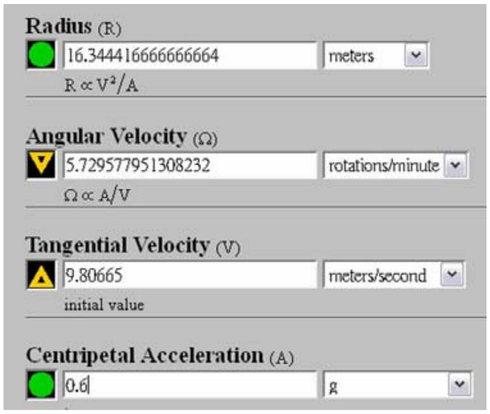

Figure 6. *Calculations of comfort artificial gravity level. (Courtesy of SpinCalc)*

III. Building MAIS

Building MAIS is a sequence of process of transforming an asteroid into movable fortress-like spaceship. Five phases of construction process have been considered as follows:

A. Primary LEO to NEA Phase

Since Orion MPCV is the core component of MAIS, unmanned Orion MPCV for emergency evacuation purpose and manned Orion MPCV takes 4 crew members with Inflatable module installed by drills are sent to the target asteroid, processing water, and oxygen for life support and plant growing facility.

B. Propulsion System Enhancement Phase

Main propulsion system are installed to either the asteroid's rare and front end for acceleration and deceleration. Reaction and artificial gravity control thrusters are installed during this phase. Materials or equipments for enhancing MAIS's communication capability, probes and other payloads are also extended.

C. Interplanetary Spaceflight Phase

For interplanetary cruising, it requires gravity assist to reach Jupiter or Saturn's orbit. During its stop to Jovian moon Europa or Saturnian moon Titan, probe or remote scout mission may also be carried out for life forms.

D. Homecoming Phase

After interplanetary mission has been done, MAIS set its course for home: Earth. Crew members use Orion MPCV reenter Earth and splash down while unmmaned MAIS is set the course to return to NEA orbit.

E. Earth Defense Phase

Assume that an Earth-threatening asteroid is heading toward us, unmanned MAIS may be remote controlled to maneuver to interception orbit and deflect the hazardous asteroid as a possible global defense strategy.

Entire MAIS building process is concluded in Figure 8. Please note that although this "Manned Asteroid Interplanetary Spaceship" concept does not try to refer any time frame, it is believed that it may be accomplished somewhere after manned NEA exploration mission during 2020 to 2030.

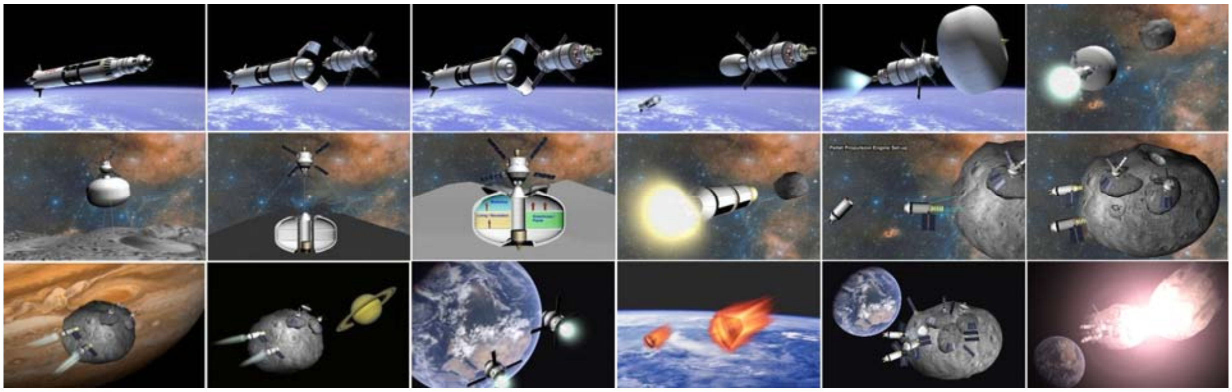

Figure 8. *A sequence portrait of MAIS construction phases and planetary defense option.*

IV. Comparison between MAIS and stopover interplanetary spaceflight concept

Inerplanetary spaceflight techniques such as orbital transfer, propulsion and fuel management, payload reliability, and risk assessment have been widely applied to transport rovers, spacecrafts, and satellites to Mars, Jupiter, Saturn, outer planets of solar system successfully. Although these are significant effort and trumph for achieving scientific research and investigation; none of them are human-rated interplanetary exploration missions.

Human interplanetary mission involves life support capability and resource utilization and/or recovery efficiency with faster powerful propulsion system to reduce crew memeber exposure under malign radiation caused by solar flare and cosmic rays that make human-rated deep space mission unrealistic so far.

As MAIS concept is an outcome of joint effort on Near Earth Asteroid mining and human interplanetary spaceflight that differs from conventional stopover (entering planet's parking orbit or landing on its surface for refueling or other reasons) manned interplanetary spaceflight scenario in ways. In this chapter, a comparison between MAIS and stopover human interplanetary spaceflight concepts is discussed as follows:

A. ΔV Budget Requirement

Any interplanetary spaceflight uses gravity assist involves Hohmann Transfer Orbit maneuver techniques for saving racket fuel and minimize thruster consumption. Theoritically, spacecraft fires its engines only twice just for orbit adjustment. However, while applying low thruster engines (for fuel conservation) this techniques requires more change in velocity (ΔV) in case of transfer to destination orbit gradually. Conventional stopover interplanetary exploration requires much more ΔV for acceleration and deceleration if the spaceship needs refuel in the middle of the journey. *MAIS concept suggests a direct flight solution from Near Earth Asteroid orbit to destination planet through gravity assist than conventional stopover scenario decreases the energy for orbit transferring, hence less ΔV is required and maximizes fuel conservation efficiency. This means that crew members utilize the resource on board MAIS (asteroid itself along the way and fly to the parking orbit of the destination planet or moon for closer investigation and returns to Earth; while spaceship needs to stopover to land on asteroids, moons, or planets (Earth to Mars, asteroids, then Jupiter, etc.) in the middle of flight for procuring rocket fuel, water, and other materials to sustain the mission.*

B. ISRU Technology Readiness Level

Technology of In-Situation Resource Utilization (ISRU) for human interplanetary spaceflight would be different based on variety of requirements. For stopover type interplanetary spaceflight, expedition crew members have to procure necessary resource for spaceship management from dynamic environment conditions. ISRU technology that is developed to utilize planetary surface material may not be conformed to asteroid context due to their raw material characteristics and processing procedure needs are not the same. On the other hand, MAIS requires concentration on asteroid type ISRU technology simplifies the difficulty and complexity on depending on related technology readiness level meets certain demands. *If we were to go to explore Jovian moon Europa, we will not have to wait until ISRU technology for Mars is fully matured and treated as a step stone to farther space; instead, MAIS provides an alternative simple solution to explore beyond Mars may be adopting technology that has been already developed for lunar mission in decades.*

C. Radiation Protection Issue

One reason that makes human interplanetary spaceflight unrealistic currently is radiation issue. Both MAIS concept and stopover type spaceflight take crew members exposed under hazardous radiation dose during fly through interplanetary space. Considering massive object like MAIS requires longer thrust burst and orbit transfer maneuver, it indeed increases health risk to crew on board. However, unlike traditional spaceship design of heavy bulky material with less sufficient function or claims water tank for cutting radiation; it is very possible for MAIS to use regolith to form a dome and cover the habitat quarters for radiation protection countermeasure.

D. Propulsion Technology Feasibility

In order to reduce duration in spaceflight, several state-of-the-art propulsion system such as Thermal Nuclear Rocket or fusion engines are researched and under development for human interplanetary spaceship. MAIS, however, a massive object requires considerable propulsion system and its energy management strategy is yet remained discussable. One possibility that is proposed here is to apply a type of mass driver to process asteroid ore into pellets and shoot them into space to gain reaction like railgun does. This may require dozens of pellet engines to acquire sufficient thrust to move MAIS out of orbit, accelerate it, and push it into appropriate orbit. Meawhile, mass that is consumed by pellet engines makes MAIS lighter and easier for maneuvering[9].

E. Life Support and Mission Reliability

The goal of MAIS is to mastering an asteroid with utilizing its own asteroid resource to support crew members to explore deep space. Traditional stopover interplanetary spaceflight depends on resource that is procured during the trip which poses highly uncertainty. During the building process of MAIS, due to the relatively closer to NEA orbit than to Mars, crew members may evacuate to Orion MPCV and back to Earth in case of emergency easier.

F. Correlation with Planetary Defense

Since MAIS concept utilizes asteroid itself for human interplanetary spaceflight, we are able to enhance our understanding on asteroids and their scientific importance. Furthermore, MAIS allows us to have compatible power on planetary defense strategy: By using asteroid to against asteroid. Unlike traditional interplanetary spaceship proposals, additional value of unmanned MAIS is to role our last trump card to deflect hazardous Earth-threatening asteroid. This is undoubtable a double-edged sword and a daredevil concept.

V. Conclusion

MAIS provides an ideal test ground for integrating technological joint effort on small body in solar system for solving life support, radiation shielding, asteroid resource management, and linkage to planetary defense issues. A series of MAIS building process may also benefit to increase our understanding of establishing extraterrestrial colony on small bodies.

Research on feasibility of MAIS propulsion system, orbit maneuver and optimizing, and orbital mechanics requires further research.

Should it be done by international efforts, our experience to explore outer solar system may be changed forever: it's NEA and beyond, instead of moon, asteroid, Mars and beyond.

Acknowledgments

The author would like to give his deepest appreciation to partners and supervisors of the interuniversity space architecture research group: Consortium of Extreme and Space Settlements, CESS for contributing their precious effort and time for promoting and educating the space enthusiasts.[10]

"It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow." --- Robert H. Goddard

References

[1]Jet Propulsion Laboratory, NASA, Near Earth Object Program, http://neo.jpl.nasa.gov/ [Cited 8 November, 2012]

[2]Farah Alibay, Andreas Frick, Eric M. Timmons, Elizabeth A. Frank: “Finding NEO: A Manned Mission to a Near-Earth Object,” AIAA Space 2012 Conference & Exposition, *AIAA 2012-5297*, 11-13 September 2012, Pasadena, California.

[3]宇宙建築研究会, *宇宙に暮らす道具学*, 雲母書房, 2009年, ISBN: 978-4876722778.

[4]清水建設宇宙開発室, *月へ・ふたたび*, オーム社, 1999年, ISBN: 978-4274023422.

[5]Housen, K. R. and Wilkening, L. L.: “Regolith on small bodies in the solar system,” *Annual review of earth and planetary sciences*. Vol 10 (A82-35776 17-88), 1982, p. 355-376.

[6]John E. Nealy,. John w. Wilson, and. Lawrence., “Solar-Flare Shielding With Regolith at Lunar-Base Site,” *NASA Technical Paper 2869* (Hampton, Virginia: Langley Research Center, 1988), URL: http://www.lpi.usra.edu/lunar/documents/NTRS/collection3/NASA_TP_2869.pdf#search=%27SolarFlare+Shielding+With+Regolith+at+LunarBase+Site%27 [Cited 6 Feburary 2013].

[7]Robert R Gilruth, 1969, *Manned Space Stations - Gateway to our Future in Space*, Manned Laboratories in Space, p. 1-10. Edited by S. Fred Singer. Springer-Verlag.

[8]T Hall, 28-30 September 1999, “Inhabiting Artificial Gravity,” *AIAA 99-4524. AIAA Space Technology Conference*, 28-30 September 1999, Albuquerque, New Mexico. URL: http://www.spacefuture.com/archive/inhabiting artificial gravity.shtml [Cited 1 December 2012].

[9]SpaceWorks Engineering, Inc.: “The League of Extraordinary Machines: A Rapid and Scalable Approach to Planetary Defense Against Asteroid Impactors,” URL: http://www.niac.usra.edu/. [Cited 10 November 2013].

[10]Consortium of Extreme and Space Settlements (CESS), URL: http://www.cess.asia [Cited 20 May, 2012]