Asteroid Redirect Mission

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Appendix E - Studies of potential future partnership opportunities for the Asteroid Redirect Crewed Mission, or other future missions, in areas such as advancing science and in-situ resource utilization, enabling commercial activities, and enhancing U.S. exploration activities in cis-lunar space after the first crewed mission to an asteroid. Six months work. July 1, 2014 - December 31, 2014. $50,000.

Section I: Executive Summary

The ARM Asteroid Redirect Mission provides a unique opportunity to test a newly developed paradigm for in situ resource utilization (ISRU) - whole asteroid digestion in pressurized space. This method of asteroid materials processing virtually eliminates dust and orbital debris generation and loose material escape into free space, and allows the material to be quickly bagged and immediately put into use as habitat high energy radiation and impact shielding. This will be particularly useful in geosynchronous orbits, where space habitats are not expected to be overly mobile, and where unlimited sunlight, infinite orbital lifetimes, valuable local resources and numerous economic opportunities are readily available. Asteroid sizes suitable for immediate habitat refugia shielding - 1 to 10 meters - also happen to be ideal for the ARM Asteroid Redirect Mission, and any long term, large scale, deep space, hazardous asteroid deflection missions will undoubtedly require the type of shielded human habitats that I have described.

Size and mass of solar system asteroids and collision ejecta debris span many orders of magnitude. Dust grains and pebbles represent collision hazards for spacecraft, while asteroids greater than roughly 10 to 20 meters in diameter start to represent real impact hazards for the planet Earth. Very small bodies are particularly difficult to detect and track, while the larger and more hazardous bodies may be soon fully quantified by near term missions such as the B612 Foundation Sentinel spacecraft. Hazardous asteroid deflection may be performed by directed gravity, mass and energy without derotating the body, and is a radically different mission than small asteroid capture, derotation, delivery, and subsequent materials processing and distribution. Asteroid sizes that are readily available for capture and delivery lie between these collision and impact hazard scales, roughly 1 to 10 meters, and are not representative of the very large diameter rotating near earth asteroids which do pose significant threats to the Earth. Small asteroids of the size amenable to capture, derotation, transport, manipulation and processing represent ideal sources of extraterrestrial material suitable for habitat radiation and impact shielding.

There are several possible choices for asteroid materials utilization - capturing and diverting the desired asteroid to a more suitable orbit with a lightweight fully fueled SEP (currently limited to <10 meters), rendezvousing with a candidate asteroid and processing it on site and then returning the material to the desired destination, and simply consuming the asteroid on location with a large free flying space habitat (suitable for large bodies with valuable resources). Large asteroids (tens to hundreds of kilometers in diameter) do not present impact threats to earth. They have enough surface gravity to settle the dust resulting from any industrial operations and are thus highly amenable to in-situ operations. For ARM mission sized asteroids, the cost of capturing and returning the asteroids to a more suitable orbit is the cheapest route, but those costs must be weighed against launch costs of launching terrestrially derived amounts of more suitably processed and structured materials up from Earth. Right now those launch costs are prohibitive, but in the near future they may be competitive. ARM mission hardware and operational cost must be less than anticipated future launch costs, or the materials much more valuable.

After asteroid capture, derotation, redirection and delivery, no further missions have been defined other than the crewed sample retrieval and return. In this proposal I will develop the full spectrum of asteroid activities through delivery and processing, with the specific application of deep space habitat shielding. Specific recommendations will be made for the initial capture hardware design which will simplify any further activities on the initial crewed mission, thus enabling asteroid processing activities to proceed. Followup missions to the ARM Asteroid Redirect Mission will involve preparing the bagged asteroid for insertion into a pressurized asteroid processing spacecraft, refueling the Solar Electric Power (SEP) propulsion spacecraft for station keeping or further transportation and solar electric production duties. These activities will be greatly facilitated by hardware designed for the ARM asteroid redirect mission, and may be performed by the NASA ARM Asteroid Redirect Mission astronauts while at the asteroid.

Section II: System Concept

In what follows I will describe two separate concepts - hard bagging an asteroid in order to capture it whole and derotate it, with no loss of dust, gravel debris or boulders into the zero gravity of vacuum, and subsequent soft bagging of the bagged asteroid within an inflatable pressurized sphere, allowing suited astronauts and robotic machinery to gain entrance to the contained and pressurized asteroid in a containment bag, and to remove, gather and transport material out of it, and away from it, without any possibility of loss of material to space and with the assistance of convection to control the environment.

The absolute requirement for zero orbital dust and debris production requires the hard bagging of the asteroid as per the original Keck proposal. Asteroids sizes are restricted to 1 to 10 meters for capture. The concept proposed here is the 'bag within a bag' approach, which is a variation of the previously proposed Archimedes cylinder sphere technique of inflation of spheres in pressurized metal cylinders. Demand for scalability beyond the 10 meter limit requires that the asteroid is not simply to be dragged through the inflatable sphere hatch and into the sphere, rather that the inflatable sphere be opened at the equator, effectively turning it into a pair of hemispheres. The much smaller external docking hatches are located on the poles of the hemispheres, and the hemispheres are bolted together at the equator. In this manner much larger processing spheres for much larger asteroids may be constructed, since the size of the asteroid processed by this approach is only limited by the size of the pressurized container. The spherical pressure stresses are more elegantly transferred between hemispheres at the equatorial rings where loads of the pressure cordage are transferred directly across the connecting bolts at the seal.

Soft pressure bagging of the hard bagged derotated asteroid solves a multitude of materials processing problems in vacuum and zero gravity. The bagged asteroid may be stabilized inside of the bag by nylon ropes to the hemispheric rings and the docking hatches. The pressurized atmosphere allows for the use of simple convection of air to remove and bag any material from the asteroid. For robotic operations, a full one atmospheric pressure, or even a human breathable atmosphere, is not required, merely enough gas for convection to be able to move the material around in zero gravity. The bag within a bag concept provides burst containment of the bag contained asteroid, and full impact and radiation protection is not necessary. The resulting bagged asteroid material may be simply moved from the processing facility into the adjacent habitation and greenhouse areas. Intense concentrated sunlight may also be piped into the processing sphere through quartz windows in the access hatches, as I have previously described, enabling heat related ISRU processing techniques to proceed in near ambient atmospheric conditions.

In order to envelop and pressure contain a large asteroid, a 'hemispherical clamshell' approach is used. The previously proposed Chinese lantern style inflatable spherical pressure vessels consisted of two flat 'washer' style annular ring and hatch plate assemblies located at the poles of the sphere with continuous cordage, cables and membranes joined to the hatches. In this approach to spherical pressure vessels, the hemispherical sub-units are conjoined at the equator by self interlocking and bolted ring or hoop units, and the pressure is contained at the hatch membrane seals and also at the equatorial ring interface. The geometry of the equatorial structural pressure ring is thus orthogonal to the that of the two hatch plates, although the concept is the same. The equatorial units are considered large hatch rings without hatches. The two hemispherical clamshells are hinged together, and deploy a full 180 degrees from their stowed positions, encircling and enveloping a large irregularly shaped bagged asteroid, and then meet and latch perfectly, around the entire circumference of the equatorial band of the resulting full spherical pressure vessel. The interlocking pressure hoops are then bolted together remotely to complete the pressure seal and asteroid structural containment vessel. These difficult, but not impossible, engineering challenges involve profound and fundamental topological concepts of spherical inflatable pressure vessels and are best reduced to practice with sub-scale models in ambient atmospheres using print manufactured parts.

Section III: Technical Approach

The ARM Asteroid Redirect Mission is an expedient way to quantify small asteroid capture, derotation, redirection and diversion costs, while simultaneously developing necessary technologies such as large scale Solar Electric Propulsion (SEP). To further enable and facilitate the follow on mission of asteroid processing into small bags of usable material, modifications must be implemented into both the ARM capture mechanism and the SEP unit, to allow for the separation of the payload from the propulsion. This torque and load bearing structure connecting the capture bag to the propulsion system must be severed in order to release the asteroid body to the pressurized capture sphere as it is being deployed. This transfer may or may not be aided by robotic arm, given the large masses of the captured asteroids. Mechanically separating the asteroid capture bag from the propulsion unit frees up the system for reuse in later missions, including attitude control, propulsion and solar energy production for this mission, and with refueling in orbit, further asteroid capture and transport duties or any of numerous other tasks.

The torques and loads across the capture mechanism and propulsion module interface are already low, due to the low thrust, high ISP nature of solar powered ion thrusters, enabling a mechanical connection. One alternative to simplify this connection is to include a separate, redundant capture and derotation propulsion and attitude control system with a significantly reduced fuel load for the asteroid capture mechanism, and use the primary propulsion module for large linear momentum changes and transport maneuvers. This approach still requires that the capture bag and asteroid mass be detached eventually, in order to completely contain it within the pressurized materials collection and processing chamber. That also provides a level of redundancy, and allows the propulsion module to stand clear and relay visual imagery and telemetry of the asteroid rendezvous and capture from an alternative perspective. This is merely one example of the many trades that must be considered to optimize this procedure.

This proposal only concerns itself with the capture and release mechanism of the integrated system, which is fundamental to the full reusability of the energy, propulsion and attitude control assets of the spacecraft required for further downstream processing of the asteroid without any space contamination. This mechanism must be robotic arm friendly and allow the revisit, recapture, reorientation and transfer of the bagged and contained asteroid into a deployable and pressurized materials processing spacecraft. The structure must also be robust against anticipated torques and loads of derotation and transportation, but also quickly, easily and reliably released without perturbing the massive asteroid, so that it may be handed off to the pressurized asteroid containment vessel. This is a non-trivial engineering exercise, involving a new process that has not yet been fully defined, using spacecraft that do not yet even exist.

The primary requirement driving the design of this mission in my view is zero space contamination. The asteroids most suitable for materials processing are friable carbon rich bodies which cannot be captured, handled or processed without creating a huge mess in the zero gravity vacuum of space. Adding even more microscopic to macroscopic debris in trans-lunar or geosynchronous space beyond the already substantial debris burden of man made space garbage could ultimately be catastrophic. There are no other viable options for small bodies other than the hard bag capture and derotation, and the subsequent total encapsulation of the asteroid body in pressurized space for post capture processing. This is an inflexible and absolute requirement. Fortunately this approach lends itself well to sub-scale modeling, design and testing in ambient environments on Earth, and subsequent verification of those results on the space station in zero gravity, before the actual deployment of full-scale flight hardware. Sub-scale models are also ideally suited for 3D printing of the hardware components enabling the rapid prototyping of geometric designs for the connections and seals and the determination of pressure loads and material stresses such that a viable design for the concepts can be quickly derived through iteration. This proposal is for that necessary work to begin, since this concept is universally applicable to space.

Section IV : Capabilities

Please refer to the resume and CV attached to this document. The inflatable 'hemispherical clamshell' concept for asteroid containment and processing spheres is a direct result of my previous work on cost reductions and safety enhancements, which resulted in a concept of inflatable 'Chinese lantern' habitats.

Section V: Data Rights

There are no proprietary data rights restrictions attached to this proposal other than personal authorship.

Section VI: Price Proposal

Description of Price Base - Overhead and Direct Costs, Profit and Labor.

Overhead and Direct Costs

Overhead Rate - 20%
Overhead Price - $10,000.00

Overhead Direct Costs Breakdown

1. General and Administrative (G&A) Expenses - $5000.00
2. Travel Expenses - $5000.00

Description of G&A Base - Rent, Utilities, Food, Materials, Equipment, etc.

G&A Rate - 10%
G&A Price - $5000.00

Description of Travel Base - Airlines, Hotels, Meals, Entertainment and Ground Transportation.

Travel Rate - 10%
Travel Price - $5000.00

Total Price for Travel Overhead and G&A Direct Costs - $10,000.00

Profit and Labor

Description of Profit Base - Labor
Labor Price Breakdown - 6 months, 1000 hours, $40.00 per hour, $40,000.00

Profit Rate - 80%
Profit Price - $40,000.00

Overhead and Direct Costs Price - $10,000.00
Profit and Direct Labor Price - $40,000.00

Total Price - $50,000.00
Firm Fixed Price - $50,000.00

Section VII: Draft Statement-of-Work

The work that I do and have been doing in this area for the last 35 years has been primarily theoretical due to lack of investment capital for space commercialization efforts. The landscape has now changed due to anticipated near term launch cost reductions possibly an order of magnitude below $1000 per lb. Similar cost reductions of pressurized inflatable space are anticipated as large scale testing of advanced concepts can proceed in low Earth orbit - either at the International Space Station or at new commercial space facilities. Geometrical and topological considerations have fixed a rough outline of this system - small inflatable spheres within empty upper stage cryogenic fuel tanks, bolted to six sided cube nodes, with the nodes bolted sequentially together and directly to the hatches of asteroid processing spacecraft. This technique should also work well for orbital debris capture, containment, salvaging and recycling. It can be simply tested in almost any large debris or satellite containing orbit near the Earth, and it is limited only by the diameter of the launch vehicle payloads, which are expected to be near 10 meters.

My intent is to attempt to reduce this concept to practice with sub-scale models of mission operations. Clearances will be tight between the asteroid hard bag and the hemispherical clamshell, as well as the derotation torquing and linear propulsion structure. There are also large deployable solar panel systems and a heavy storage tank of xenon fuel which drives the ultimate geometry of the integrated spacecraft. The derotated asteroid bag can either be released into free drift to be captured by the processing sphere, or the solar electric propulsion system can remain attached to the asteroid providing attitude control until the processing spacecraft arrives, and then be reintegrated into the spacecraft at another port, in order to provide additional power and control after the asteroid is released. These are fundamental design decisions that are crucial to the success of any subsequent processing missions to the asteroid.

To come to any reasonable conclusions about the inflatable sphere technology itself, the hemispherical ring hoops and hatch plate membrane sealing and cordage technologies must be verified with respect to the continuity of stress distributions as compared to the full tube toroidal pressure spheres expected in simple twin hatch sphere designs, which are easily stabilized by internal wire cables between hatches. Clearly the concept of hemispherical clamshell spheres is at TRL 1. Therefore the bulk of the work proposed here is for the geometry of the asteroid bag release mechanism so that the system is reusable and the asteroid can be safely and easily transferred from the propulsion unit to processing spacecraft.

Working on far thinking advanced projects such as these are normally dollar a year or pro bono efforts. My fee for full time work producing these essays is $100,000/year or $50,000/six months, which will include travel to and from three meetings and the presentation of any works I accomplish in this time. The submission of this proposal represents publication of this concept for the commercial industry and NASA, should they decide to pursue asteroid release and processing as a viable addition to the mission, and reusability of the solar electric propulsion vehicle into any subsequent asteroid processing mission.

Further hardware demonstration work will involve attempts to physically demonstrate sub-scale models of pressurized toroidal tube spheres, hatch ring and plate assemblies, and the hemispherical clamshells. Working pressures are expected to be in the range of 15 - 30 - 45 PSI with respect to ambient pressure of one atmosphere. Working diameters are expected to be from one to three feet (less than one meter). Working materials for demonstration purposes are expected to be aluminum and commercial polymers and rubbers, nylon and stainless steel wire rope, and other simple commercial off the shelf equipment, in addition to the possible 3D rendering and printing of mechanical parts for fast engineering iterations. Given the limited amount of time and money that NASA wishes to invest in exploration of this concept it would require me to invest the entire profit and labor of this proposal on asteroid capture and release mechanisms so that the concept of SEP solar electric propulsion reuse becomes intrinsic to the mission.

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Direction To continue modern theoretical and experimental investigations into strongly correlated electron systems, lightweight, affordable earth to low earth orbit launch vehicle architectures, closed ecological life support systems, and super insulated, low carbon emission, earth sheltered homes and habitats for earth and space.

Director of Research **Launch LLC, The Tsiolkovsky Group, Marshall, Wisconsin, USA** **2006 - 2014**

Company Founder and Chief Executive Officer
Performed Multidisciplinary Research in the Natural Sciences
Engaged in Systems Engineering, Research and Development Projects
Published Seminal Reports for Emerging Commercial Space Flight Industry

Astronaut Training **Lansing Cay and Rudder Cut Cay, The Exuma Cays, The Bahamas** **2001 - 2005**

Machine Shop, Dock and Boatyard Construction, Hurricane Preparedness
Space Port, Resort, Astronaut Training and Launch Facilities Development

Elifritz vs. Elifritz **Civil Court Litigation, The State of Florida, Lansing Cay, Exuma Cays** **1998 - 2000**

Prosecuted a successful legal effort for defendant’s discovery documents,
resulting in the half Bahamian island ownership of Lansing Cay, Exuma.

Elifritz vs. Elifritz **Supreme Court Order, The Commonwealth of the Bahamas, 1997 #20** **1996 - 1997**

Argued a successful legal defense of Bahamian island ownership,
resulting in a time sharing agreement with development restrictions.

Technical Director **Caribbean Marine Research Center, Lee Stocking Island, Bahamas** **1989 - 1995**

Personal Assistant to the Director of the Research Center
Scientific, Laboratory and Telecommunications Technical Director
Island and Field Coordinator for Resident, Guest and Scientist Safety
Performed, Published, and Presented Multidisciplinary Research Results

Software Engineer **AmTel Communications, Inc., McFarland, Wisconsin, USA** **1987 - 1988**

Developed and Maintained Self Recompiling polyFORTH II Nucleus
Maintained “EVE” - The World's Largest polyFORTH II Application
Implemented Training Programs for Programmers and Engineers
Assured Cross Target Compiler Capability Across Multiple CPUs

Director of Research **Syntech Living Systems, Windsor, Wisconsin, USA** **1981 - 1986**

Performed Basic Life Science Experiments
Designed Products for Scientific and Technical Markets
Implemented Machine Shop and Manufacturing Capabilities
Developed and Maintained Life Sciences Laboratories and Facilities

Education **The University of Wisconsin, Madison, Wisconsin, USA** **1978 - 1980**

Sixty four (64) degree credits in the Applied Mathematics, Engineering and Physics program, equivalent to an associate’s degree in rocket science and engineering, including humanities and foreign language requirements, applied mathematics through advanced calculus and linear algebra, engineering mechanics through statics and dynamics, mechanics of materials and orbital mechanics, modern physics and chemistry, and extensive self study and life experiences, including field work.

Thomas Lee Elifritz - Scientific Publications and Presentations **1994 - 1995**

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Thomas Lee Elifritz - Scientific Research Papers, Proposals, Essays and Letters **2007 - 2014**

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Ceres Polar Mission - Ceres Polar Orbiter, Lander and Reconnaissance Mission.
OSIRIS-REx II to Mars - Mars Sample Return Mission Proposal for NASA and the Lunar Planetary Institute.
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Space Exploration and Development Architectures (For SpaceX Falcon Launch Vehicles).
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The National Academies - Committee on Human Spaceflight - Public Input
The Evolution of a Reusable Space Launch System (SLS)
The Delta V Reusable Space Launch System
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The Space Station
The Space Place
The Space Cadet