Reusable Space Launch Systems

Assisting Commercial Launch Providers in the 21st Century

Thomas Lee Elifritz
Launch LLC - Final Report

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National Aeronautics and Space Administration (NASA)
Office of the Chief Technologist
300 E Street SW
Washington, DC 20546-0001

Early Stage Innovation
NASA Innovative Advanced Concepts (NIAC)
NASA Research Announcement (NRA)

NASA Solicitation NNH11ZUA001N
Stage 1 Proposal for the Period Ending May 16, 2011

Catalog of Federal Domestic Assistance (CFDA) Number: 43.009
OMB Approval Number 2700-0085

Acronyms

The acronyms used in this proposal will be defined as needed in the document for clarity, and are listed here for the convenience of the general readership and external science community. Additional relevant acronyms appearing in the reference documents are listed here as well.

DoD – The Department of Defense (a major consumer of commercial launch vehicle services)

STS – Space Transportation System (the soon to be retired NASA space shuttle system)

SSME – Space Shuttle Main Engine (the primary space shuttle orbiter propulsion engines)

ISS – International Space Station (soon to be an orbiting national laboratory and space port)

NIAC – NASA Innovative Advanced Concepts (the subject of this research proposal)

VSE – Vision for Space Exploration (the presidential order for space shuttle replacement)

ESAS – Exploration Systems Architecture Study (the Constellation design committee report)

COTS – Commercial Orbital Transportation Services (commercial launch vehicle agreements)

CRS – Commercial Resupply Services (commercial resupply contracts for the ISS)

OSTP – Office of Science and Technology Policy

OMB – Office of Management and Budget

PCAST – President's Council of Advisors on Science and Technology

LEO – Low Earth Orbit

BEO – Beyond Earth Orbit

NEO – Near Earth Object

SLS – Space Launch System (the congressionally mandated national launch vehicle system)

Ares V – Constellation Heavy Lift Launch Vehicle (now renamed the SLS)

MPCV – Multi Purpose Crew Vehicle (the congressionally mandated human rated spacecraft)

CEV – Constellation Orion Crew Exploration Vehicle (now renamed the MPCV)

OTRAG - http://en.wikipedia.org/wiki/OTRAG (an early German commercial launch company)

SpaceX – Space Exploration Technologies (a primary COTS and CRS award recipient)

OSC – Orbital Sciences Corporation (a primary COTS and CRS award recipient)

Executive Summary

The United States has enacted two laws mandating the continuation of the NASA Constellation program, which is now widely considered to be a failed effort after previously spending $11 billion dollars over seven years without producing any actual space shuttle replacement or space flights.

The NASA Authorization Act of 2010, Senate Bill S.3279 now Public Law P.L. 111-267, specifies an expenditure of $11.5 billion dollars over six years to develop a Space Launch System (SLS) with an initial low Earth orbit payload capacity of 70 tons evolvable to 130 tons, and a Multi Purpose Crew Vehicle (MPCV), for human spaceflight to the International Space Station (ISS), and then beyond.

The 2011 Full Year Continuing Budget Appropriations Act, House Resolution H.R. 1473 now Public Law P.L. 112-10, appropriates $3 billion dollars for the continuation of the Constellation program for the fiscal year 2011 and contains language dictating the development of a new launch vehicle and spacecraft identical to the Ares V heavy lift launch vehicle and Orion Crew Exploration Vehicle (CEV).

The author of this NASA Innovative Advanced Concepts (NIAC) proposal has predicted since the inception of the Constellation program that its intractable technical and fiscal problems would result in its failure, and for the entire duration of the Constellation era (2006 thru the present) has performed advanced and innovative reusable launch vehicle research, with the objective of providing NASA, congress and the president with all of the knowledge, information and tools necessary to solve the Constellation problem. This effort resulted in a series of proposals, position papers, research papers and research results which clearly outline an incremental path to conventional launch vehicle reusability, using the Constellation, Space Shuttle (STS) and existing commercial launch vehicle assets, as well as incorporating the intellectual and technical expertise of the emerging commercial space flight sector.

This NASA Innovative Advanced Concepts (NIAC) proposal recapitulates the history and the results of that research effort as a report, with the goal of redirecting the SLS and MPCV effort into a realistic and fiscally responsible NASA reusable space launch system development program, which incorporates the most successful elements of the Shuttle, Constellation and the commercial launch vehicle programs, while satisfying the spirit of congressional intent, and the intent and wishes of the President, Office of Science and Technology Policy (OSTP), the Office of Management and Budget (OMB) and the NASA administrator, his deputy administrator, and their administrative, management and engineering staff.

The objectives of further research proposed by this NIAC proposal is to initiate development of the smallest possible national Space Launch System capable of demonstrating the concepts of reusability, recovery, retrofit and reuse of our commercial launch vehicle assets, for the immediate benefit of the ISS national laboratory program and the commercial launch vehicle and spaceflight industry. The goal of this proposal is dramatic reductions in low Earth orbit (LEO) launch and spaceflight development and operational costs. The motivations for this effort are the stated development and operational costs and the per flight prices advertised by the most successful of the emerging launch vehicle companies.

NASA, as a prototypical launch vehicle and spaceflight development agency, must meet or exceed these strict performance benchmarks if it expects the continued large expenditures of time and money on a space program that can be less expensively handled by existing immediately available commercial launch vehicles. High flight rate, reusable conventional launch vehicles are the best near term solution to this requirement, and this proposal describes several innovative methods by which the development goals and costs dictated by acts of congress can be met by these objectives.

History

The author of this proposal, Thomas Lee Elifritz, is presently a private citizen of the United States, in the past and currently engaged in advanced space research, development and demonstration activities.

On the inception of the Constellation Program in late September of 2005, after a secretive and biased Exploration Systems Architecture Study (ESAS) performed at the request of the NASA administrator Michael Griffin, the author of this proposal returned to the United States with the specific purpose of directing further advanced space architecture studies (The Tsiolkovsky Group), the ultimate goal being salvaging the ill advised, technically flawed and financially unexecutable Ares launch vehicle project. An ancillary objective was the further promotion of a competitive commercial launch vehicle industry, in order to facilitate the Vision for Space Exploration (VSE), considered by this author to be premature.

For the first two years of preparatory study work (2006-2007), the Constellation program and the Ares rocket projects within NASA proceeded unchecked, with little resistance coming either from within or outside of NASA. With its penultimate programmatic failure guaranteed and predestined from its very inception, the complementary failure of a commercial effort (Kistler), precipitated yet another round of Commercial Orbital Transportation Services (COTS-2) solicitations, which provided an ideal method for the publication and widespread dissemination of our study group's results at that point (late 2007).

Over the next two years (2008-2009), during which the Constellation programmatic failures became more widely recognized and better understood externally, my study group was able to further refine and publish our pro bono results through a variety of venues within nationally funded NASA commercial space research and development activities. This period of activity culminated with Norman Augustine's Committee Review of Human Space Flight. At this point in time (2009) the failure of Constellation was widely recognized, and the value of the emerging space flight industry in solving this conundrum had become self evident to even the most casual of observers. Nevertheless the Augustine Committee report was less than definitive, and it took another year or more of commercial space flight successes in order to convince all but the most devout unbelievers, that a commercial space flight industry had arrived.

Unfortunately, throughout this entire latter period (2010-2011), congressional oversight which had so dramatically failed throughout the entire Constellation era, continued to exercise their authority and control over the national space policy process, and succeeded in encoded their beliefs into legislation, in the form of Senate bill S.3279, which was signed by President Obama on October 11, 2010, and has since become Public Law 111-267 - the NASA Authorization Act of 2010. This act represents a virtual continuation of the failed Constellation program, specifying the investment of $11.5 billion dollars over six years for development of a Space Launch System (SLS) and Multi Purpose Crew Vehicle (MPCV).

Concurrently with these congressional space policy discussions, NASA released their heavy lift launch vehicle trade study contract solicitation, for which the author competed under the auspices of a limited liability corporation organized in the State of Wisconsin – Launch LLC. This modest effort failed, and the contracts were awarded to the major players within the emerging commercial space flight industry. At this point our Constellation salvage effort was abandoned completely, and the congressional failure of the budget appropriations process, through a series of continuing resolutions, affirmed that decision. Negotiations culminated as a 2011 continuing budget appropriations act (H.R. 1473/P.L. 112-10) which contained a $3 billion dollar earmark for SLS and MPCV, zeroing the advanced technology programs (including funding for the awards for this solicitation), and was signed by the president on April 15th. With Constellation funding (under a name change) again appropriated by an act of law, the author filed corporate dissolution papers on that day, and closed shop. This proposal is Launch LLC's final report.

Advanced Innovative Concepts

The gauntlet for NASA and the emerging competitive commercial spaceflight industry was further laid down on April 5, 2011, when Elon Musk of SpaceX released the preliminary details of his redesigned triple core Falcon Heavy launch vehicle, where cross feeding and stretched cores will allow it to loft fifty metric tons of payload into low Earth orbit, reaching the price point of $1000 dollars per pound. He did it again on May 4, 2011 where in a press release he described verifiable SpaceX development costs, and then stated unequivocally - "*These are the objective facts, confirmed by external auditors*."

Then he set the bar for anyone, including NASA, who may wish to compete with his launch vehicles:

> SpaceX intends to make far more dramatic reductions in price in the long term when full launch vehicle reusability is achieved. We will not be satisfied with our progress until we have achieved this long sought goal of the space industry.
>
> The American free enterprise system, which allows anyone with a better mouse-trap to compete, is what will ensure that the United States remains the world's greatest superpower of innovation.

Hear, hear.

Goals and Objectives

The goal of the commercial launch vehicle and spaceflight industry, which is by now beyond any reasonable doubts well established, and remains the foundation of all space flight activities - human, machine or otherwise, is to continue to design, fabricate, construct and manufacture ever better and better launch vehicles, and the objective of that work is to continue to reduce the costs of spaceflight.

This author is of the opinion that reusability and high flight rates are the venues for achieving that goal. Complementary to this approach are the small scale, stage clustered, pressurized, fully reusable designs embraced by the emerging suborbital spaceflight industry out of fiscal necessity, the 'Otrag' paradigm. In both approaches the key concepts are reusability, recoverability, refurbishment, retrofit, and finally, repurposing of the on-orbit or deep space spaceflight hardware assets into new and useful applications. This concept has already been successfully demonstrated by deep space planetary flyby spacecraft.

Statement of Work

The technical challenges that must be overcome on the route to full reusability in launch vehicle design are great, the timeframes involved are measured in decades and the resulting payloads will be very low. In order to alleviate the requirements of the laws of physics applicable to the problems of launch costs, while simultaneously addressing the waste of time and funding incurred by the Constellation program, the author initially proposed a series of hybrid launch vehicle architectures based upon existing engines and infrastructure, evolvable into the full reusability challenges demanded by the emerging commercial launch vehicle sector, and the heavy lift payload capacities and Constellation infrastructure utilization requirements now set forth by congressional acts of law. This advice was soundly ignored by congress, NASA and the White House, and treated with great skepticism by the commercial interests backing the Augustine review committee, resulting in a disappointing and less than convincing Human Space Flight report, which then precipitated another two year delay in the cancellation of the Constellation program. The delays, the waste of taxpayer funds and the loss of technical credibility of the NASA design teams were both unnecessary and avoidable, and the purpose of this proposal is to stop and reverse that trend.

Recapitulation

It is very difficult to engage congress, administrators and engineers who continue to insist that tossing large diameter cryogenic tankage affixed to multiple irreplaceable space shuttle main engines into the ocean, after propelling them all the way to low earth orbit with overpowered solid rocket boosters, at a development cost of tens of billions of dollars, and a per flight costs of a billion dollars per flight, is a credible means of lowering launch costs or performing beyond earth orbit exploration and spaceflight. Low earth orbit (LEO) contains a large space port (ISS) that now resides within our economic sphere, and existing high performance cryogenic engine efficiency can easily support high flight rate launches.

With $11.5 billion dollars and six years at their disposal, NASA could easily implement a much more modest and far more rational program of launch vehicle development and reusability using our existing commercial and space shuttle assets, that would propel both existent and nascent commercial launch vehicle industries into the 21st century with taste, elegance and style, and would result in a national launch vehicle that would be highly manufacturable, transportable and evolvable, and yet still satisfy unreasonable congressional capacity and infrastructure constraints that have been imposed upon them. The purpose of this proposal is to reinforce and reaffirm that outcome one last time before abandoning this effort completely, and letting the debacle of the Constellation program, under the name change of SLS and MPCV, run on for several more years and yet another ten billion dollars to its ultimate failure. I will recapitulate what has already been demonstrated from previous work referenced in this proposal.

Cryogenic tank diameters beyond five meters (8.4 and 10 meters) are unaffordable and unnecessary.

The only existing cryogenic engines with the weight, thrust to weight ratio, efficiency and total thrust capable of near term reusable heavy lift launch vehicle operations are the space shuttle main engines, (SSMEs), where a dozen or more flight worthy engines still exist, and the Russian NK-33s (AJ26s), which now exist in inventories by the dozens, and where international coproduction agreements are in place. Indeed, the Russians will soon begin flying them in a redesigned Soyuz 1, and Orbital Sciences Corporation (OSC) will soon begin flying them in a twin engine Taurus II launch vehicle from Wallops.

Therefore, by these two criteria, the form of the launch vehicle is dictated by default laws of physics.

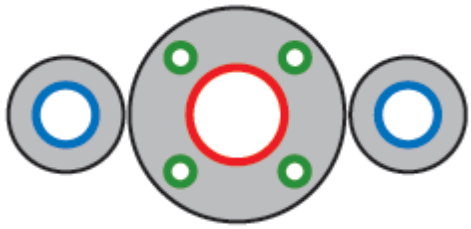

Figure 1. Three Meter Hydrocarbon Boosters With Five Meter SSME Core Stage

By invoking fiscal responsibility, this is the minimum launch vehicle form by which reusability of the hydrocarbon boosters may be developed, where reusability of the core stage in stage and a half to orbit configuration may be tested at the International Space Station (ISS) and where heavy lift launch vehicle evolvability may be realized simply by adding additional boosters, up to a maximum of eight boosters. In addition, Department of Defense (DoD) requirements for the reusability of rapid response launchers may be satisfied by utilizing three meter hydrocarbon boosters in new DoD specific launch vehicles, commercial assets of the emerging space industry may be utilized directly, and congressional mandates for use of Constellation (Ares upper stage manufacturing technology) and STS assets (SSMEs) are met.

The Past and Future Evolution of Reusability in Launch Vehicle Design

The emerging small space (new space) commercial sector is now, or very soon will be capable of fabricating and launching fully reusable vertically and horizontally launched pressure fed hydrocarbon and alcohol fueled launch vehicles, which can return to any landing site and land onto a precise spot in space and time under their own internal power. Yet commercial launch vehicle providers (old space) are still unable to recover empty, free falling boosters with just parachutes and airbags into the open ocean.

The time for this situation to change is right now, and NASA, the nation's authorized aeronautics and space agency, should be leading the way. And for decades now they have been, with the space shuttle, but that vehicle has proven to be resistant to evolution, and far too expensive and dangerous to operate. Rather than continue the tradition of reusability initiated by the space shuttle, by adding the concept of evolvability to an obvious and cost effective program of launch vehicle booster recovery and core stage reuse, NASA and congress have chosen to reverse the path of our space program straight back to yet another expensive and expendable heavy lift launch vehicle development program. Even in the Apollo era of unlimited budgets this path was unaffordable, and in recent years it has been demonstrated to be a failed exercise of little value to the commercial space flight industry, and has tarnished our reputation.

The evolution of reusability in conventional vertical launchers is expected to progress dramatically via the development of launch vehicles, demonstration of booster recovery, the development of core and upper stage reuse, the recovery, refurbishment and reuse of the engines, and ultimately, large payload return. SpaceX has completed the first task of this program, dramatically reducing launch costs in the process, and has laid down a challenge for its competitors and collaborators. In this proposal I reiterate a method of meeting that challenge, by laying out a technical path to full reusability of launch vehicles.

Three Meter, Fully Reusable, Highway Transportable Hydrocarbon Booster Clustering

Recovery of Falcon 9 cores is expected to be a challenging task primarily because of the large size of the booster core and the heavy weight of the thrust structure and nine engines in the tail of the launcher. On the other hand, recovery of single, lightweight, highway transportable three meter cores powered by a single integrated engine could proceed swiftly, allowing for innovative solutions such as aerodynamic rentry and control, flyback and landing, as well as a simple parachute and airbag splashdown recovery. Orbital Sciences Corporation has already worked out the details of twin engine starting and flight of the AJ26 engines, and the simultaneous starting of two engines on opposable boosters should be possible. The use of a preengineered and cluster capable medium launch vehicle booster core in a wide variety of different cluster configurations would allow for the sizing of rapid response launch vehicles to payload. Available small solid rocket boosters may be easily affixed to this standard core for increased payload, and the addition of an upper stage would yield a flexible DoD specific rapid response launch vehicle.

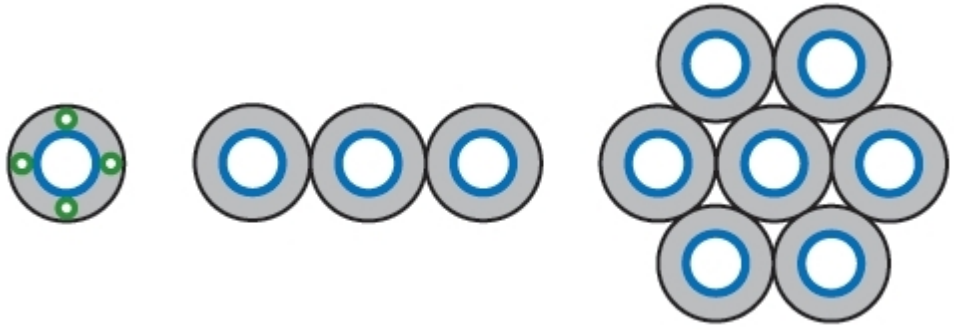

Figure 2. Typical Three Meter, Hydrocarbon Fueled, Booster Cluster Configurations

Five Meter, Ground Started, Hydrogen Powered Core Stages as Upper Stage Vehicles

The current inventory of legacy space shuttle main engines are more than adequate to sustain a modest reusability demonstration and test flight program within five meter form factors - if they are recovered. The international space station is a space port and technical laboratory well suited for engine recovery and cryogenic tank retrofit and reuse technology development activities in real time orbital situations. The primary unresolved problems of space shuttle engine reuse in conventional launch vehicles is the auxiliary power required for engine starting and hydraulic thrust vector control, which are problems applicable to any high performance hydrogen engines, and this technology domain clearly lies within the realm of national obligations and responsibilities. If the primary justification for a US space launch system is a national backup for commercial ISS crew transportation and resupply companies in case of failure to deliver contracted services, then given current fiscal constraints, this is the form it must take.

Given both SpaceX and OSC development costs and performance to date, as compared to Constellation expenditures and performance thus far, any further investment in large diameter, expendable, heavy lift launch vehicles is not advisable. The authorized and appropriated funds ($3 Billion for 2011), and the justifications and performance specifications invoked by congressional act, would be better directed towards a launch vehicle of the type described in this proposal, which would complement and enhance the technological superiority of our existing commercial launch vehicle assets, instead of drawing funds away from supporting their continued evolution and into competing against them for national payloads.

Ground Insulation Systems for Bare Metal Cryogenic Tank Launch, Retrofit and Reuse

In order to successfully implement a program of launch vehicle reusability through value added orbital infrastructure development, several innovations must be implemented in the realm of thermal control, attitude stabilization and impact resistance. Cryogenic fuels (liquid oxygen and hydrogen) need to be insulated to prevent excessive boiloff and water ice formation during tanking on the pad, and a minimal amount of hypersonic thermal protection must be provided for the bare metal tankage during the ascent. This proposal is to provide removable insulation and anti-icing and deicing infrastructure on the pad, where the insulation structures would simply be retracted from the vehicle stack shortly before launch, eliminating costly and time consuming factory tank insulation processes and insulation damage risks to the tankage and vehicles, and where boil off pressures would then be tightly controlled during launch. In this scenario cryogenic tankage would arrive at LEO uninsulated, where lightweight, thin film sun shades could be deployed to the attitude stabilized tanks allowing on-orbit fuel recovery and tank reuse, thus solving a multitude of orbital debris, impact damage, tankage stabilization and disposal problems.

Payload Supported Aerothermodynamic Fairings For Launch Vehicle Engine Return

Another complementary proposal is to replace expendable payload fairings with lightweight and open-ended ballistic reentry vehicles, enabling large payload returns to the ocean via parachutes and airbags. This solves a well known problem of fairing release failures and provides quick and reliable downmass and rescue capability for the ISS. This is a materials science and structural engineering problem that could possibly involve pressurization of the payload fairing shroud during the initial ascent phase as well as structural support from the payload itself during launch and reentry through the atmosphere. Advanced innovative concepts described in this proposal and in numerous previous referenced works will necessarily consume payload mass delivery capabilities of the launch vehicles, but the value added by space based infrastructure delivered, recovered, reused and repurposed easily exceeds those losses.

Reference Documents URL and Location : http://webpages.charter.net/tsiolkovsky/

Personnel

The principle investigator responsible for the work effort put forth in this NIAC research proposal, Thomas Lee Elifritz, has a long history of accumulated research efforts, experience and publications representing due diligence in several broad interdisciplinary research domains involving space science and technology, closed life support systems and theoretical and experimental condensed matter physics.

Work Effort and Plan

Since the innovative TRL1 concepts have already been previously described by this respondent, and subsequently driven to TRL2 by events beyond the control of the author, this proposal is specifically for moving the previously described technologies to TRL3 over the annual period of this work effort. Given that $3 billion dollars is going to be spent on the SLS and MPCV in this year alone, should this NIAC proposal be selected, the principle investigator suggests that compensating funds be disbursed in some form of cooperative NASA space act agreement with the Tsiolkovsky Group, where the proposed fee of $100,000.00 is requested for due diligence already performed, and where under the terms of the agreement, due diligence will continued to be performed for another year. The principle investigator also requests that any research results revert directly to the national public domain, under the auspices and control of the National Aeronautics and Space Administration (NASA), and at their full discretion, with the single caveat that any and all previous and/or future publications by the principle investigator be credited and cited by any national work effort related to this NIAC proposal herein, should congress, NASA and the president agree to directing the SLS funding to a launch vehicle proposal of this nature.

Facilities and Equipment

The principle investigator of this proposal will be responsible for the living arrangements, facilities and equipment and travel involved in the execution of any cooperative research efforts, inclusive of the fee. Collaboration or facilities and equipment offered by NASA will be free of charge, exclusive of the fee.

Representative Image

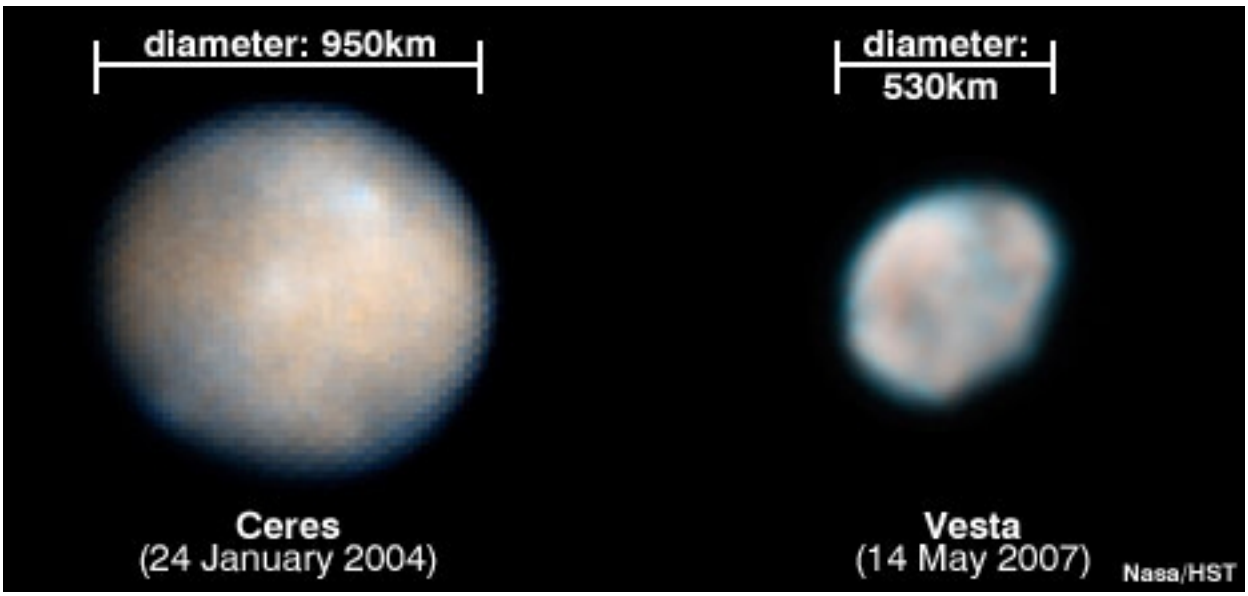

Figure 3. Ceres and Vesta Imaged by the Hubble Space Telescope

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Thomas Lee Elifritz

Direction To continue 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.

Director of Research **Launch LLC, The Tsiolkovsky Group, Marshall Space Flight Center** **2006 - 2010**

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** **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 mechanics of materials and orbital mechanics, general physics and chemistry, and extensive self study and life experiences.

Scientific Publications **1994 - 1995**

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