# HEAVY LIFT AND PROPULSION TECHNOLOGY SYSTEMS ANALYSIS AND TRADE STUDY

Federal Contract Proposal
**Amendment 2**

Launch LLC and
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Contract Proposal Due – July 29, 2010
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**Offerer Notes** : Excerpts in *italics* are taken from the Broad Agency Announcement for context. Presentation and punctuation have been edited from the original BAA for clarity.

## SYNOPSIS

*The technical objective of this study is the identification of the capabilities required to support an innovative evolutionary human space exploration activity, with possible destinations including the Moon, Mars and its environs, near-earth asteroids, and Lagrange points.*

*The focus of this study is to determine the technology, and research and development required for a heavy lift system, defined as including a heavy lift launch vehicle and the in-space propulsion elements required to conduct those human space exploration activities.*

*The study shall identify and analyze multiple alternative architectures (expendable, reusable, or some combination) on which a heavy lift system addressing the objectives can be based.*

*The study shall identify how alternative heavy lift system solutions address key decision attributes/figures of merit/measures of effectiveness, including a recommended list of key decision attributes and rationale associated with each.*

## INTRODUCTION

***NASA*** *is seeking an innovative path for human space exploration which strengthens the capability to extend human and robotic presence throughout the solar system. NASA is laying the ground work to enable humans to safely reach multiple potential destinations, including the Moon, asteroids, Lagrange points, and Mars and its environs. The Exploration Systems Mission Directorate (ESMD) is leading the nation on a course of discovery and innovation that will provide the technologies, capabilities and infrastructure required for sustainable, affordable human presence in space.*

***NASA*** *is examining the trade space of potential heavy lift launch and space transfer vehicle concepts. The focus is on affordability, operability, reliability, and commonality with multiple end users (Department of Defense (DoD), commercial, science, international partners, etc.) at the system and subsystem levels. A major thrust of this activity is space launch propulsion technologies that will enable a more robust exploration program, support commercial ventures, and related national security needs.*

*The December 2009* ***NASA Heavy Lift Launch Vehicle*** *(HLLV) study is contained within the government-provided technical package posted with this BAA. The model contract is also posted with this BAA and the Offeror is to submit a signed contract in response to the BAA.*

*This* ***BAA*** *is soliciting proposals for* ***Heavy Lift and Propulsion Technology Systems Analysis and Trade Studies*** *and seeks industry input on technical solutions in support of heavy lift system concepts studies. These studies will capture potential system architectures and identify propulsion technology gaps (to include propellant tanks, main propulsion elements, health management, etc.). This BAA request offerors to expand upon the initial NASA technical assessments provided in the technical data package included. This effort will include architecture assessments of a variety of heavy lift launch vehicle and in-space vehicle architectures employing various propulsion combinations and how they can be employed to meet multiple mission objectives. A variety of in-space architectural elements, such as space transfer stages, space transfer vehicles, propellant depots may be included. The focus will be on developing system concepts that can be used by multiple entities (NASA, DoD, Commercial, International) with a strong emphasis on affordability.*

***NASA****'s policy prioritizes safety to protect: (1) the public, (2) astronauts and pilots, (3) the workforce (including contractor employees working on NASA contracts), and (4) high-value equipment and property. NASA FAR Supplement (NFS) 1852.223-70 defines safety as the freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property or damage to the environment.*

## OFFEROR ADDENDUM - NLS (SLS) – National Launch System (Space Launch System)

Recently proposed congressional legislation from the Senate and the House of Representatives essentially dictates future national space launch policy, in the form of SRB and shuttle derived heavy lift launch vehicle development, over previously proposed evolutionary hybrid designs. These developments obviate our previous work, and dictate a complete redirection of this effort.

**PART 1 – TECHNICAL MERIT** (Maximum 25 Pages)

**Technical Approach**

*The Offeror shall clearly define the proposed technical and systems engineering approach for evaluating and analyzing heavy lift system concepts as outlined in the Section III Technical Objectives and the attached technical package which contains the HLLV study. The Offeror's proposal may address one, all, or a combination of the Heavy Lift systems elements but must also address the overall system architecture impacts associated with the selected elements.*

Reproduced here are two recent unpublished papers describing the results of heavy lift launch vehicle studies performed concurrently with NASA's Heavy Lift Launch Vehicle (HLLV) Study, which indicate a different result than the proposed space exploration architectures of the HLLV.

*Offeror's shall propose a Statement of Work (SOW), suitable for incorporation into a contract, for a six (6) month period of performance and include their approach to completing the contract deliverables as stated in Section VIII, Paragraph 9.0. Offerors are cautioned to include only that information which is essential to a clear, concise and binding Statement of Work - (SOW).*

NASA has outlined a very clear statement of work, which I am attaching to this document as J-1. The offeror intends to execute this work as Principle Investigator (PI) for the full contract value.

**Capabilities**

*The Offeror shall provide evidence of existing capabilities for designing and developing space-qualified systems applicable to a variety of heavy lift launch vehicle and in-space vehicle architectures employing various propulsion combinations and multiple mission objectives.*

The Offeror intends to simulate aspects of the proposed space exploration architecture using the Orbiter Space Flight Simulator, while developing a model for future federal contracting efforts. The first three months (half of the contract value) will be applied to the development of models, and the last three months will be applied to testing and analysis related to the statement of work.

**Data Rights/Export Control**

*The Offeror shall address their proposed data rights approach to meet the requirements under Section VIII, Part 8.0, Data Rights. The Offeror shall address their proposed approach to meet Export Control under Section II, Part 3.0, Export Control.*

The Orbiter Space Flight Simulator is open source software licensed under GNU General Public License. Addons using the Orbiter API are thus exempt from any data rights and export control.

**Federal Contractor Registration Clause**

The Offerer will register with the federal contractor registry prior to acceptance of this contract, including LLC filing in the State of Wisconsin, DUNS and EIN numbers and CCR registration.

**Launch LLC**

**Thomas Lee Elifritz**
**The Tsiolkovsky Group**
**Madison, Wisconsin USA**

The Tsiolkovsky Group is a private academic study group, initiated in 2005 for the sole purpose of directing the discussion, analysis and study of the low Earth orbit propulsion, launch and life support systems needed to enable the future development, exploration and colonization of space. The group has been meeting informally, weekly and monthly, in order to update and integrate the individual study efforts, and to coordinate group efforts, further enabling the scientific, technical and engineering development of rational, affordable and sustainable launch vehicle architectures.

The initial formation of this study group was in response to the announcement of Constellation, but the organization can trace its roots back to 1985 and the University of Wisconsin at Madison. For a few years in the early 1980s, tentative space shuttle and space commercialization efforts briefly flourished under a set of faulty low Earth orbit launcher cost, flight rate and lift capability assumptions, which were becoming apparent shortly before the Challenger disaster in early 1986.

Remaining illusions of inexpensive and readily available low Earth orbit space transportation evaporated on January 28, 1986, and the concept of innovative launch vehicle architectures and space development and exploration scenarios became the focus of intense and perpetual debate, deviating remarkably from the initial 1970s concepts of O'Neill colonies with reusable launch vehicles and space planes, and focusing almost exclusively on near term off the shelf solutions.

After several decades of research, development and discussion of low Earth orbit launcher and propulsion architectures, the announcement of the Constellation program in September of 2005 promised another additional five year setback for a rational national space transportation policy. This forced a systematic review of the past progress within the study group, and the initiation of more narrowly focused research efforts, again based upon the faulty assumptions of the necessity and possibility of a Constellation program salvage. Work continued for two full years, a year of which involved the unique scenario testing abilities of the 2006 Orbiter Space Flight Simulator. Publication of the study results and its guidance followed in the form of contract and research proposals and scientific research and positions papers for the emerging commercial space sector.

Launch LLC intends to move this guidance directly to the federal contract level, with appropriate monetary compensation at levels commensurate with the sum of their value, and the expenses incurred by their delivery. An arbitrary assessment of $500,000 for a five year period works out to $50,000 per person, for the six month period of the proposed heavy lift trade studies, a level of employee compensation in aerospace studies and engineering that is below current industry rates. Graphic design, programming, managerial and administrative positions are assessed at $25,000. I leave calculation of the value of previously published guidance as an exercise for the reviewers.

A directory of these publications may be found at URL : http://webpages.charter.net/tsiolkovsky/.

**Executive Summary - The Genie is Out of the Bottle**

With the first flight of the SpaceX Falcon 9 launch vehicle, the genie is clearly out of the bottle with respect to less costly and more routine low Earth orbit space flight - based upon confident engineering design, development, production and operational foundations, and financial security. The question now is what can be learned from watching the birth, development and evolution of successful space launch companies from afar, and how can those lessons be applied in moving forward with a new and more modern heavy lift launch vehicle and space exploration program.

Previous heavy launch vehicle trade studies, optimizing use of existing programmatic hardware and development projects, have already produced a minimally optimized solution of a five meter single SSME powered, ground started, single stage to orbit capable core stage, booster assisted with a pair of parallel (side mounted) hydrocarbon booster stages, any number of which exist. This EELV and Ares upper stage hybrid '**Delta V**' design satisfies congressional insistence on shuttle derived, since it uses SSMEs, and the modern space advocate's insistence on reusability, with a minimum of manned and unmanned beyond Earth orbit space exploration capabilities.

Now is the time to repeat these trade studies in the substantially reduced developmental and operational trade space necessitated by the accelerated time frames and reduced budgets now envisioned for this proposed heavy lift effort. In order to facilitate useful trade studies, without duplicating previous efforts, I have drawn up a preliminary description of a spectrum of LEO launch mass classifications,[1] so that the target architecture may be optimized for size scaling by selecting market niches in the center of the mass sequence unrepresentative of current products. This yields generalized booster staging and recovery mechanisms which may be scaled up into large heavy launch vehicles, and scaled down into minimum launchers capable of reaching orbit.

Successfully competing in today's emerging launch vehicle design and development market essentially reduces to challenging the Falcon 1e, the Taurus II, the Soyuz and the Falcon 9. In order to reduce the costs and complexity of meeting this challenge, one good approach is to attempt to enhance the product spread, rather than duplicating and out competing the products. The top level discrete decision tree of the design hierarchy in this ideal case is extremely sparse, yielding the solution of a three meter, medium light class hydrocarbon launch vehicle core stage, powered by a single NK-33, both singly and clustered three abreast, and finally with seven core stages lofting a single NK-43 upper stage, yielding the anticipated heavy lift launch capabilities. Remarkably, a cluster capable hydrocarbon booster can also directly support the hydrogen core stage previously proposed, with or without exploration capable J-2X upper stage enhancements.

Release of a new administration space policy, stressing international cooperation and diplomacy through global technological infrastructure development and economic trade, justifies this result, and it is the goal of this contract proposal to demonstrate the veracity of this definitive example. This simple design iteration is referred to as the **Orbital Standard Core,** and is contingent upon cooperative hydrocarbon engine coproduction agreements, with proactive Russian collaboration. Orbital Sciences Corporation and Aerojet GenCorp are in ideal positions for these developments. New core stage development, manufacturing and transportation processes and efficiencies allow small and modest core stages to be mass produced by domestic concerns closer to the launch site, significantly improving logistical and scheduling requirements for heavy lift launcher operations.

**Concurrent Hydrocarbon Engine Production**

We now have two standard stages, a hydrogen core stage and a hydrocarbon booster stage, which can be assembled into a variety of launch vehicle configurations that inhabit several unoccupied niches in the launch vehicle mass classification spectrum. They also respectively use the most advanced and efficient engines in their classes, the space shuttle main engine and the Russian NK-33. When used together they are easily capable of reaching low Earth orbit without the use of upper stages, and also capable of supporting two different fuels in their optional upper stages, kerosene in the case of the NK-43 and hydrogen in the case of the J-2X or other existing engines.

In passing, I note that both the NK-33/43 and the J-2 were developed at great cost and sacrifice for the Russian and American lunar exploration programs, flying in vehicles that were designed without the benefit and availability of modern design tools and practices, without the subsequent decades of space flight experience that has accumulated while pursuing low Earth orbit activities.

Clearly the next order of business is the active testing of these engines, and the accumulation of flight test data, in order to demonstrate the reliability and veracity of their design. Already the large inventory of existing engines, domestically at Aerojet and warehoused in Samara, Russia, greatly advances the cost and schedule for these operations. Orbital Sciences Taurus II puts flight testing of these engines as early as next year, and test firing of the engines has already occurred.

Release of a new national space policy now justifies expanding the scope of these collaborative Russian - American engine reverse engineering goals, and the preservation and enhancement of their metallurgical understanding, their manufacturing capabilities and industrial bases, and the active pursuit of cooperative coproduction agreements that would allow for a eventual reengining of an existing launch vehicle (Soyuz), and active pursuit of new second generation closed cycle hydrocarbon engine and launch vehicle designs, in both Russia and the United States of America. These sorts of cross cultural advanced science and technology programs are precisely the type of activities that support and promote the ideals of human space exploration and development, and it is remarkable these activities are already taking place in the emerging commercial space sector.

**Inline and Parallel Sidemount Booster Staging**

The proposed standard booster study item consists of a cluster capable, hydrocarbon powered core stage with 335,000 lbf sea level thrust (1500 kN), and a lift off weight of @ 300,000 lbs., midway between the lift capabilities of the Falcon 1e, and the Taurus II which uses twin engines. Such a stage is capable of flying individually with a small capsule and an integrated upper stage. For heavier lift capabilities and deep space exploration applications, such a stage may be paired with the previously proposed five meter SSME powered study unit, as a minimal dual fuel heavy lift launch vehicle. Such a stage does not require any upper stage to reach low Earth orbit, but when paired with an inline upper stage, it is quite capable of ambitious deep space exploration missions, while simultaneously supporting a variety of LEO development, support and resupply activities. The ability to test the booster stages independently from the larger and more complex core stage, within the framework of operational low Earth orbit missions, reduces their overall developmental challenges and costs. The capability to test three abreast stage clustering with a small, lightweight and relatively inexpensive booster stage permits sequential risk retirement.

## Parallel and Circular Stage Clustering

The proposed study item may also be parallel clustered three abreast with an NK-43 upper stage, as an EELV equivalent. Extrapolating to much larger launch vehicles, such a stage may also be clustered into a circular arrangement, as a group of seven core stages, with either an NK-43 powered upper stage, or an exploration capable J-2X powered stage, for heavy lift capabilities. The ability to start the development and testing of a single stage within operational situations, greatly reduces cost, schedule and risks of the more ambitious heavy lift stage cluster derivatives.

## Highway Stage Transportation

With a booster stage diameter of three meters or less this booster stage is trivially road worthy, with commonly available diesel semi tractor highway transportation, using specialized trailers and methods commonly practiced for transporting wind generator tower segments and blades. This technique alone will substantially reduce overall launcher production and operations costs, especially if vehicles could be launched from dry land with the booster stages fully recoverable.

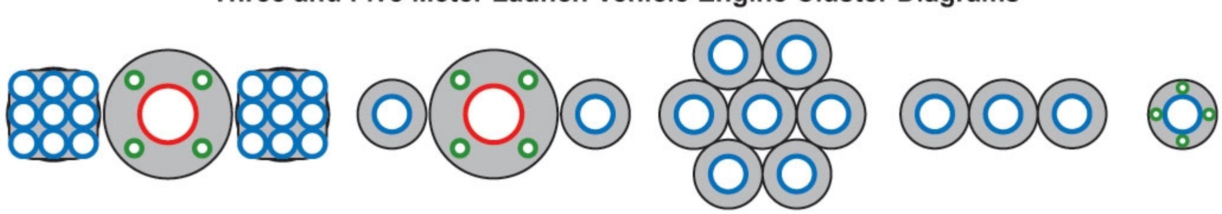
## Flyback Booster Recovery

Clean sheet booster design and fabrication processes allow for a booster with critical clustering attachments predesigned and validated for future scaling of the booster into heavier lift designs. Standard booster recovery techniques may be implemented at the single booster level, to reduce development costs within the flight regimes of operational revenue producing orbital missions.

## Final Conclusions

We have already eliminated a wide swath of stage configuration phase space from our studies as a result of irreconcilable budget constraints. Through designing for modular stage clustering, we have identified a variety of mass launch capabilities across an entire spectrum of vehicles, that are not in competition with any existing DOD EELV and NASA COTS and CRS commitments. Two prototypical standardized core and booster stages have now been presented, which represent a minimum viable study set for the design, development, test and evaluation (DDT&E) analysis. ‘**Orbital Standard Cores**’ consist of cluster capable five meter core stages, powered by a single space shuttle main engine, and three meter booster stages, powered by a single Aerojet AJ26-58.

**Three and Five Meter Launch Vehicle Engine Cluster Diagrams**




## References

1. The British Scale For Launch Vehicle Mass Classification
   http://webpages.charter.net/tsiolkovsky/British_Units.pdf

# Heavy Lift
# Reusable Launch Vehicles

Quarterly Report in Progress
February 14, 2010
Final Draft

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**Abstract**

This paper analyzes recent developments in launch vehicle design engineering science as they apply to basic launch vehicle design theory and expendable launch vehicle evolution towards the penultimate conclusions of modern future reusable heavy lift launch vehicles.

**Scientific Position**

This author is of the opinion that two urgent environmental problems that have risen to the level of national security issues – global warming and orbital debris, not only demand the immediate cessation of the offending processes, atmospheric carbon combustion on the one hand, and expendable launch vehicles, upper stages and their satellite payloads, but also require immediate active mitigation such as reducing the atmospheric carbon dioxide levels and removing a large amount of the at risk and high risk orbital debris.

The sheer magnitude of these problems demands immediate national efforts similar to the Manhattan project at the condensed matter physics level, or the Apollo moon landings at the space science and astrophysics level, in order to solve and implement the solutions.

The Obama administration intends to pursue a 'simpler' heavy lift launch vehicle effort signaling a willingness to entertain new or alternative heavy lift launch vehicle designs, in addition to wrapping the described problems up into a national space science initiative tied directly to new national education, infrastructure development and jobs programs. Meaningful progress in these areas requires the quality assurance and design oversight that is best provided by modern practitioners of the new domain of engineering science.

**The Scope of the Problem**

Modern rocket science and engineering has now matured to the level of conceptual and practical advancement, such that one may proceed directly to new clean sheet designs. However, existing expendable medium lift launch vehicle capabilities now exceed their market demand in both capacity and flight rate, and there is no consumer demand for new clean sheet expendable heavy lift launch vehicle designs; beyond government subsidized efforts predicated upon future requirements for global planetary engineering solutions to: near term environmental and natural hazards such as global warming and climate change; near Earth orbital debris proliferation; earthquake, tsunami and asteroid impact response; terrorism and nuclear proliferation; and financial insolvency related to economic decline, job losses, escalating fuel costs and carbon and hydrocarbon based energy dependencies; and associated pollution and environmental degradation effects these situations hazard.

Human space flight suffers from a public perception of irrelevance to modern societal problems, in sharp contrast to its necessity for solving present day threats to civilization. This poor perception has roots in the diminishing educational opportunities and real life experiences for a growing fraction of people on an overpopulated and resource stretched planet, rapidly approaching critical thresholds in almost every aspect of day-to-day life.

Likewise, space science and astronautics also suffers from a poor understanding among the general scientific community of the value of government to government collaboration and the huge impacts to society, the positive effects on education, and the great benefits for international diplomacy that have resulted from a minimal investment in space flight. Furthermore, many imagined or predicted futuristic and large scale discretionary science projects such as orbiting extrasolar planetary telescopes and observatories, interplanetary spacecraft and missions and further development of near Earth space solar power stations may very well require the additional lift and flight rate capacities that heavy lift provides.

The potential for human space flight to revolutionize the quality of life for large fractions of the global population rivals the effects that semiconductors and condensed matter and quantum physics has had on industrialized society, but remains as yet, not fully realized, generally unrecognized, and under appreciated by ordinary citizens and scientists alike. The unique abilities of space flight activities and infrastructure to detect, prevent, resolve and respond to modern and future global and international problems such as natural and man made disasters, remains ignored and neglected primarily because of its application to situations and conditions which are not immediately addressable or confrontable, appear as distant in space or remote in time, or are perceived to be insoluble or intractable. Thus, the prospect of space flight as a tool for economic stability and global security is not yet widely understood, recognized, acknowledged or accepted as an obvious observable fact, and a deep skepticism of its value, and a lack of appreciation for its utility still persists.

The solution to the credibility gap that exists for evolutionary heavy lift launch vehicle development is a clear demonstration of its relevance to solving the seemingly insoluble problems of modern civilization, and a critical review of its abilities to evolve into the fully recoverable, retrofitable and reusable systems demanded by economic necessity.

## Time and Funding Constraints

Complementary to our present space launch and orbital infrastructure are the anticipated and future funding profiles and the timelines associated with the magnitude and severity of the various national and global problems that are expected to be confronted and solved by a robust and well funded international space program. Clearly the clock is still ticking.

When the problems of heavy lift launch vehicle development are cast into this basic form, fundamental solutions are then amenable to simple geometric and mechanical methods using existing launch vehicle assets and current state of the art as the initial starting point.

Time and funding constraints simply dictate the amount of time and money necessary to validate new core and stacking arrangements with their engine plumbing configurations in terms of analytical structural, fluid dynamical, thermodynamic and fuel flow models, and then constructing and testing necessary tools and techniques for orbital disassembly and reassembly of the volatile safed attitude controlled space rated core stage and engine.

This kind of work defines human space flight, and thus there are no outstanding reasons why these procedures will not be amenable to engineering science methods, and the cycle of design, validate, construct, test and launch cannot be closed and driven into periods which produce yearly test flights and satisfactory results within four year election cycles. The existing budget is adequate to support initiation of the program with existing assets, and the on orbit facility we have is more than adequate to support any in situ simulations.

## Engine and Booster Limitations

I have recently described the viability and ease of single stage to orbit test flights of new space shuttle main engine (SSME) powered core stages of solid rocket booster (SRB) and hydrocarbon liquid reusable booster (LRB) assisted stage and a half to orbit architectures without the need for upper stages and with heavy lift class cargo capacities to an existing orbital space port, easily capable of handling the tasks of the orbital recovery, retrofit and reuse of heavy core stages, engines and payloads - the International Space Station (ISS).

Remarkably, shuttle derived inline heavy lift launch vehicles with space rated core stages could ideally be flown concurrently with our existing space shuttles, allowing immediate engine retrieval of expensive and delicate reusable space shuttle main engines from orbit. By developing tools and procedures to remove engines in orbit, while docked to the ISS, and returning them to Earth in the cargo bay of the shuttles, great advances can be made in reusability and cost reductions while greatly enhancing the value and utility of the ISS.

Even absent space shuttle availability to return test flight engines from low Earth orbit, initial test flights may also proceed sequentially with STS retirement with single engine flights on five meter core stages flown to low Earth orbit or extinction, whichever comes first, or with the use of commonly available booster augmentation. These vehicles would have the payload capacities of the Ares I without the burden of numerous engineering and logistical problems associated with the refurbishment of segmented solid rocket boosters.

**Existing Contractual Obligations**

Constellation program contracts consist of an engine contract for a high energy cryogenic upper stage engine with Pratt & Whitney Rocketdyne, the reengineered 1.3 MegaNewton J2-X interplanetary class vacuum restartable engine, the associated test stands at Stennis, along with a 5.5 meter upper core stage from Boeing and a five segment SRB from ATK. Also on hand and in service are in excess of a dozen flight worthy SSMEs, with enough spares for dozens of SSME equivalent flights, a few space shuttle ETs and four segment SRBs all available for the immediate development and fabrication of flight test hardware.

Upper stages with the thrust levels of the J2-X and payload capacities of the heavy SRBs are not expected to be needed for quite some time, as the timeframes for the ET derived engine clustered heavy lift launch vehicles are exceptionally long, and require extensive redesigns and modifications to the 8.4 meter external tanks in order to proceed. Similarly, five meter single engine ground started variants of the Ares I upper stage will also require an extensive redesign and modifications as well, but new hybrid spin forming and friction stir welding technologies promise to greatly reduce weight and speed up the development of five meter EELV class core stages. Thus, a rational method of proceeding would be to renegotiate the Ares upper stage fabrication contracts with Boeing, and then proceed with development of rapid turnaround structural and thermodynamic analysis and validation methods, procedures and techniques for multi-diameter variable length cryogenic stages, amenable to the booster configurations appropriate to the vehicle diameter and length. This would allow development of the long lead time propulsion elements to be relaxed and the immediate and urgent program of SSME liquid core stage development to begin.

**Resource and Center Management Issues**

Once a decision has been made to retain advanced cryogenic hydrogen launch vehicles, and to continue national involvement in next generation reusable launch vehicle research, then SSME powered, cryogenic single stage to orbit core stage development can proceed. Initial hardware development, fabrication and test flight operations should be restricted to the rapid deployment of 5.5 meter, all liquid powered, Ares I heritage EELV derivatives, consisting only of demonstration flights which are complementary to existing commercial and industry efforts rather than competing directly against them. These efforts should not diminish the long term necessity for new engine and booster stage elements as well as the upper stage extensions to the robust low Earth orbit infrastructure necessary to solve the relevant and serious societal and national security problems anticipated in the near future. At risk NASA centers and their constituencies should be held accountable to their unique abilities to administrate, develop, fabricate, test, launch and operate these future systems.

An implicit understanding must be developed among the relevant center administrators and directors that the resulting technology development efforts must produce systems that represent incremental advances to existing state of the art in commercial launch vehicles, and that fiscal realities and national priorities will be invoked to demand system recovery, retrofitability and reusability at the highest levels in the mission requirements hierarchy, such that fielding advanced future launch vehicle demonstrations may proceed posthaste.

**Five Meters - Single Engine EELV Form Factors**

Single stage to orbit space flight was first accomplished in 1958, with the flight of an Atlas B on Project SCORE. Although technically not an SSTO, the core stage was still ground started and then flew directly to low Earth orbit, with the assistance of side mounted boosters, in this case outboard engines. The modern version of this rocket may very well be called an EELV hybrid – a Delta IV core stage reengined with a space shuttle main engine, and boosted with a pair of side mounted Atlas Vs.

Clearly it's not as simple as reengining and space rating a Delta IV core stage, but we've already made substantial investments in high energy upper stages with the Ares I, and the inevitability of new cooperative second generation heavy EELV programs is undeniable. The key to making an expendable launch vehicle program affordable and sustainable is to make each individual element of it - the core stage, engines, boosters and payload carrier - reusable, with increased payload capacities and decreased costs over existing offerings.

Economic, fiscal and temporal realities will demand that any second generation reusable launch vehicles will also necessarily involve recovery, retrofit and reuse of redesigned, stretched and reengined core and upper stage elements of the total system, adapted to the evolutionary engineering and scientific advances of the day, month, year and/or decade. Only the increased efficiency, reduced weight, closed cycle and regenerative cooling of hydrogen powered space shuttle main engines makes these single stage to orbit scenarios possible, thus affording order of magnitude improvements in the logistics of space flight. The immediate application of modern new Al-Li spin forming and friction stir welding technologies to EELV sized core stages exemplified by the Ares I upper stage will enable the eventual development of reusable heavy lift launch vehicles using 8.4 meter tankage.

## 8.4 Meters - Two and Four Engine ET Form Factors

Only when routine, high flight rate, all liquid fueled, stage and a half and booster assisted space flight is achieved, should the economies of scale afforded by wide tankage, engine clustered, heavy lift launch be pursued. By applying existing and competent - operational, government, industry and commercial manufacturing infrastructure and resources, and by demanding logistical expediency and cost reductions of recovery, retrofit and reusability, we should be able to attain the order of magnitude improvements necessary in low Earth orbital transport capabilities required to address and confront any of the future problems which may be encountered by an industrial civilization, on a terrestrial planet, many of which are now well underway, approaching the level of severe national security issues.

External tank derived straight stack launch vehicles assisted by segmented solid rocket boosters are amenable to opposing pairs of space shuttle main engines, either a single pair flying with reduced fuel loads, or in a square configuration of four engines in two groups. This particular geometry allows for terminal acceleration shutdown of a pair of engines for thrust reduction, or a single engine within a pair, albeit with some asymmetric thrust. Presumably such a large core stage could also be boosted with liquid reusable boosters, at the expense of a somewhat reduced payload, and such a system also approaches single stage to orbit capabilities without the worries of exceeding the SSME acceleration limits.

However, one can immediately recognize how quickly development and operational costs escalate with these large core stages and their complicated SRB integration procedures, and how flight rate would be diminished over smaller and simpler single engine designs where other methods exist for reducing terminal accelerations of five meters core stages. Furthermore, the fuel needs of four engines will require a tank stretch, and the insulation needed for a larger volume of the cryogenic hydrogen fuel is proportionately increased.

## Ten Meters - Five and Seven Engine Cluster Form Factors

Extrapolating to the ten meter tank diameter range of the Saturn V - also envisioned by NASA to feed the very large and heavy RS-68s in Ares V designs – the smaller, lighter, more efficient and regeneratively cooled nozzles of the space shuttle main engines can be supported in clusters of five and seven, which necessarily involves engines three abreast. These large future heavy lift designs are possible if problems of cryogenic fuel insulation are solved such that the engines can be recovered in orbit, and tankage can be retrofitted into the large low earth orbit space ports, hotels, observatories and the interplanetary craft envisioned for the future. Clearly also are the anticipated high costs of such an endeavor far beyond any funds currently available, and any timeframes are well beyond reasonable.

Nevertheless, the geometric and mechanical advantages of such large engine clusters are readily apparent – ample payload in volume and mass, generous engine out capabilities, multiple sequential engine shutdown options, and a ground started center engine available to function as an upper stage, optimized for vacuum operation or with nozzle extensions. The ability to monitor, throttle and shut down individual engines according to their health provides a method to limit high terminal accelerations often encountered in space flight.

## Conclusions

Engineering science has now subsumed the role of systems engineering as the top level domain for the conceptualization, representation and execution of complex programs. Whereas systems engineers would argue that the missions dictate the launch vehicles, the engineering scientist would argue the reasons for going into space, and then presume that propulsion and launch vehicles would be fundamental prerequisites for all that follows. Missions would merely be engineering projects within programs, and the goal would be to satisfy the arguments - hypotheses, that were originally made to justify the endeavor.

In the same manner that general relativity doesn't invalidate the classical mechanics used in our day to day engineering tasks, this paradigm shift does not diminish the veracity of systems engineering methods and techniques to specify the requirements and procedures necessary in order to implement the complex systems of modern human space flight - particularly low Earth orbit flight, rather it develops the reasoning behind the endeavor itself, and then designs appropriate scientific and engineering experiments, conducted at costs commensurate with the value of the questions answered, and the problems solved.

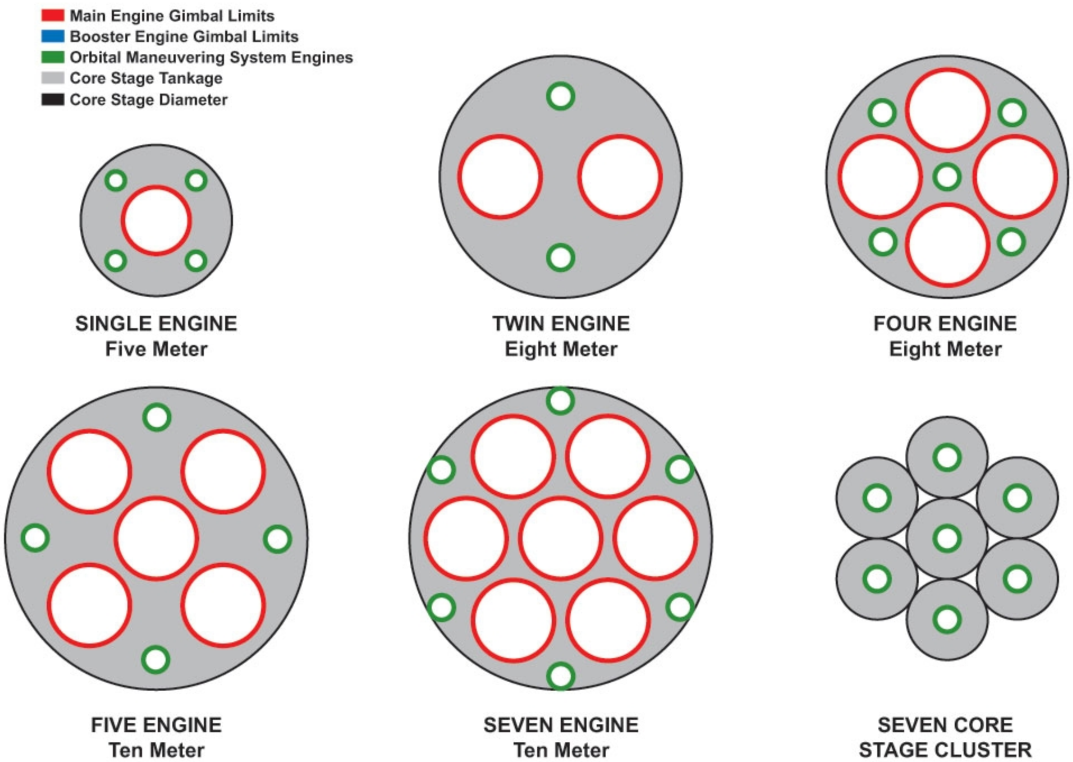
Comparing the five meter reusable EELV hybrid designs outlined here, to the previously proposed heavy lift launch vehicle architectures, although they appear as small launchers, in actuality these are core stages intrinsically possessing single stage to orbit capabilities, assisted by extremely powerful twin side mounted kerosene boosters with relatively short burn times, rendering them amenable to simple robust reentry and recovery procedures. This is in contrast to the relative complexity of the preengineered tank designs necessary to allow adaptation of the bulk of the propulsion and guidance, navigation and attitude control system to the lower energy budget of orbital space flight, and the thermal and fuel management techniques which must be implemented in order to ensure that the stage is able to reach its destination, and is safed and space rated shortly after main engine cutoff.

Astonishingly, the fundamental Earth to low Earth orbit concepts laid out here (Figure 1) can be scaled down into the minimum possible launch vehicles capable of reaching orbit, a region in phase space that we've only just begun to explore, putting the realm of space within the grasp of individual and small groups, including small corporations and nations. It is thus essential that this transition to commercial space flight be well managed by the appropriate institutions and their international counterparts, with the explicit legal, civil and government oversight authority, such that space is efficiently utilized, the public is sufficiently protected, and existing debris is monitored and removed in a timely fashion.

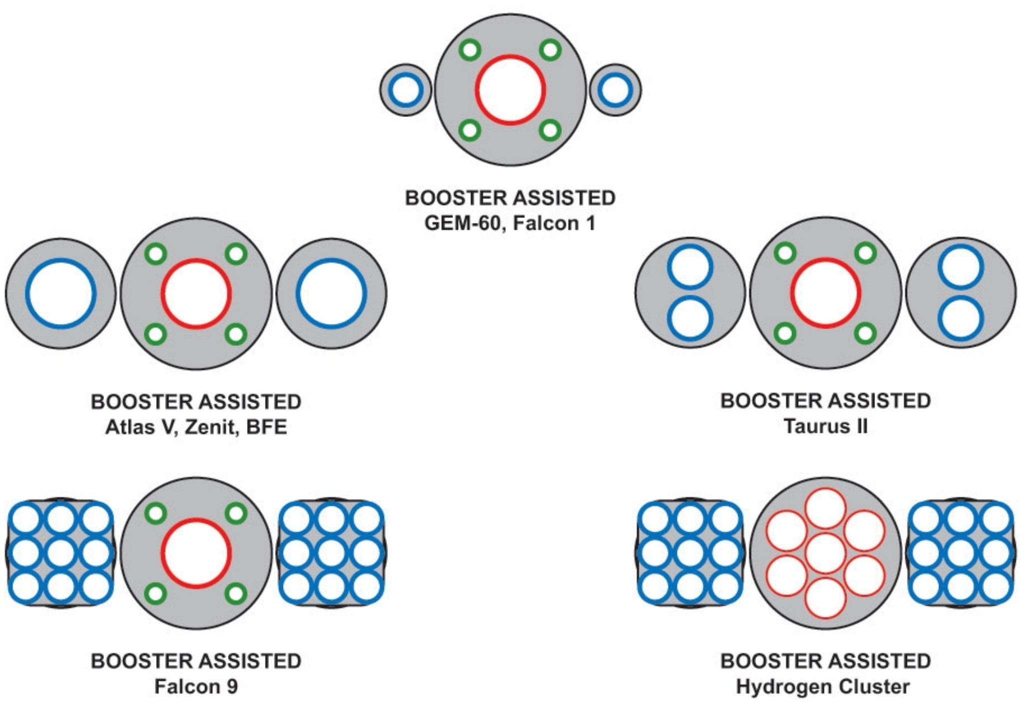
## References

1. **NASA JSC-COTS-2,** Commercial Orbital Transportation System
URL : http://webpages.charter.net/tsiolkovsky/Commercial_Space.pdf
2. **NASA JSC-CCDev-1,** Commercial Crew Development
URL : http://webpages.charter.net/tsiolkovsky/Commercial_Crew.pdf
3. **Human Space Flight – A New Direction**
URL : http://webpages.charter.net/tsiolkovsky/Human_Space_Flight.pdf

**Figure 1. Five, Eight, and Ten Meter Launch Vehicle Engine Cluster Diagrams**




**Pathfinder Launch Vehicle Demonstration Missions**



**PART 2 – PAST PERFORMANCE PROPOSAL** (Maximum 3 Pages).

*The Offeror should include a list and description of any experience in research and development of launch vehicle systems.*

The Offeror has a well documented history of performance dating back to November of 2007.

Document Directory, URL : http://webpages.charter.net/tsiolkovsky/.
This Document, URL : http://webpages.charter.net/tsiolkovsky/Propulsion.pdf.

*Commercial Orbital Space Transportation System*, proposal to NASA Solicitation JSC-COTS-2.
URL : http://webpages.charter.net/tsiolkovsky/Commercial_Space.pdf.

*An American Vision*, position paper on national science policy submitted to http://change.gov.
URL : http://webpages.charter.net/tsiolkovsky/American_Vision.pdf.

*21st Century Space Policy*, comment submitted to the National Academies Space Board.
URL : http://webpages.charter.net/tsiolkovsky/21st_Century_Space.pdf.

*Human Space Flight - A New Direction*, position paper for the Augustine HSF review committee.
URL : http://webpages.charter.net/tsiolkovsky/Human_Space_Flight.pdf.

*Augustine Committee Recommendations*, personal letter to Norman Augustine.
URL : http://webpages.charter.net/tsiolkovsky/Augustine_Committee.pdf.

*Commercial Crew Development*, proposal to NASA Solicitation JSC-CCDev-1.
URL : http://webpages.charter.net/tsiolkovsky/Commercial_Crew.pdf.

*Heavy Lift Reusable Launch Vehicles*, Quarterly Report - The Tsiolkovsky Group, Madison, WI.
URL : http://webpages.charter.net/tsiolkovsky/Heavy_Lift.pdf, (Reprinted in this document).

*The Planet Ceres - A Worthy Goal for a Great Nation*, commentary on. national space policy.
URL : http://webpages.charter.net/tsiolkovsky/Planet_Ceres.pdf.

*The Meghar Scale of Planetary Mass Classification*.
URL : http://webpages.charter.net/tsiolkovsky/Meghar_Scale.pdf.

*Heavy Lift Launch and Propulsion Technology*, NASA Request For Information 05042010PS40.
URL : http://webpages.charter.net/tsiolkovsky/Heavy_Launch.pdf.

*The British Scale for Launch Vehicle Mass Classification*.
URL : http://webpages.charter.net/tsiolkovsky/British_Units.pdf.

*Launch LLC*, Thomas Lee Elifritz, The Tsiolkovsky Group, Madison, Wisconsin USA.
URL : http://webpages.charter.net/tsiolkovsky/Launch_LLC.pdf, (Reprinted in this document).

*The Offeror shall provide evidence of system analysis tool validation for systems of the class being investigated.*

The Orbiter Space Flight Simulator, Closed Loop Guidance, Navigation and Control, Visual Situational Awareness for Instrumented Space Flight, Crosscutting Technologies Request For Information, NASA RFI Solicitation NNH10CC001L, Office of the Chief Technologist, URL : http://webpages.charter.net/tsiolkovsky/Guidance.pdf.

Trajectory Software for Low Earth Orbit and Beyond LEO Analysis, Design and Real Time Operations, NASA Request For Information, NASA RFI Solicitation NNJ10ZHD001L, URL : http://webpages.charter.net/tsiolkovsky/Orbiter_Space_Flight_Simulator.pdf.

*The Offeror shall provide a maximum of three (3) sources of past performance on similar studies. For each contract, the Offeror shall provide the following :*

*Solicitation Numbers*

JSC-COTS-2, JSC-CCDev-1.

*Name of Soliciting Agency*

NASA Johnson Space Center.

*Program Manager and Telephone Number*

Alan J. Lindenmoyer, Program Manager, Commercial Crew and Cargo, (281) 244-7064.

*Agreements Officer and Telephone Number*

K. Lee Pagel, Agreements Officer, NASA Johnson Space Center (JSC), (281) 483-3945.

*Synopsis of Work Performed* – In order to submit and compete for these space act agreements, the offeror has performed numerous system analysis and trade studies over the last five years. No space act agreements were awarded to the offeror, and no contracted work was performed.

*Solicitation Type*

Space Act Agreements.

*Total Solicitation Value*

$174 Million Dollars (JSC-COTS-2).
$50 Million Dollars (JSC-CCDev-1).

*Past Performance Rating*

No space act agreements were awarded and no contracted work for NASA was performed.

**PART 3 - PRICE PROPOSAL** (No Page Limits or Formatting Requirements)

*The price proposal shall include the overall firm fixed price. The offer shall not exceed $625,000. The $625,000 is the maximum award. The proposal price may be less than $625,000.*

The fixed firm price offered for this NNM10ZDA001K contract proposal award is $100,000.00.

*The offeror shall provide total direct labor hours by skill mix, travel and subcontracts. Technical Interchange Meetings will take place at Marshall Space Flight Center and brief weekly telephone status meetings will be required.*

The Offeror, as Principle Investigator (PI) in this research and development effort, intends to invest 1000 work hours over a six month period, including two required technical interchange meetings at Marshall Space Flight Center located in Huntsville, Alabama, and a daily fifty mile commute from Madison, Wisconsin to our space flight facility located in Marshall, Wisconsin.

There will be no subcontracting involved in the satisfaction of the requirements for this contract.

**PART 4 – MODEL CONTRACT** (One Page Brief)

Reporting Requirements

The resultant contract awards will include the following deliverable requirements:

| Month | Deliverable |
|---|---|
| 3 | Technical Interchange Meeting 1 and Briefing Package |
| 5 | Technical Interchange Meeting 2 and Briefing Package |
| 6 | Final Study Report |

Technical Interchange Meeting Briefing Package (s): Charts statusing accomplishments, planned work and issues per the Data Rights Restrictions in Paragraph 8.0.

Final Study Report (due six months from contract award effective date): one (1) hard copy and one (1) CD-ROM to be delivered to NASA.

The schedule of the proposed contract runs from October 1, 2010 through March 31, 2011.

The Contractor shall provide all resources (except as may be expressly stated in the contract as furnished by the Government) necessary to deliver and/or perform the items below in accordance with the description/specifications/statement of work (SOW) incorporated under Attachment J-1.

**CONTRACT TITLE - HEAVY LIFT & PROPULSION (HELP)**

During the first three months of this proposed NASA systems analysis and trade studies contract, the offerer (contractor) Launch LLC, The Tsiolkovsky Group, and its principle investigator (PI), Thomas Lee Elifritz,, shall produce Orbiter Space Flight Simulator addons for publication and general distribution, encompassing the previously proposed Orbital Standard Cores - the DeltaV and the OSC, and their stage cluster derivatives. Orbiter addons, inertial mass distributions, and flight models will then be used to conduct systems analysis and trade studies, as per this SOW.

The total firm fixed price of this contract is **$100,000.00**.

**PAYMENT SCHEDULE**

| **Payment** | **Deliverables** | **Due Date of Report** | **Amount** |
|---|---|---|---|
| 1 | Technical Interchange Meeting 1 and Briefing Package | 3rd Month | $50,000.00 |
| 2 | Technical Interchange Meeting 1 and Briefing Package | 5th Month | $25,000.00 |
| 3 | Final Study Report | 6th Month | $25,000.00 |
| **TOTAL** | | **$100,000.00** | |

**ATTACHMENT J-1 - NASA Statement of Work**

The technical objective of this systems analysis and trade study is the identification of the capabilities required to support an innovative evolutionary human space exploration activity, with possible destinations including the Moon, Mars and its environs, near-earth asteroids, and Lagrange points. The focus of the systems analysis is to determine the technology, and research and development required for a heavy lift system, defined as including a heavy lift launch vehicle and the in-space propulsion elements required to conduct those human space exploration activities.

The trade study shall identify and analyze multiple alternative architectures (expendable, reusable, or some combination) on which a heavy lift system addressing the objectives can be based.

The study shall identify how alternative heavy lift system solutions address key decision attributes/figures of merit/measures of effectiveness, including :

Provide a recommended list of key decision attributes and rationale associated with each.
As a point of reference, NASA's Heavy Lift Launch Vehicle study utilized the following list of system attributes: Life-cycle cost – DDT&E, fixed and recurring (production and operations); operability-support manifest launch rate; safety and reliability; performance (mass, delivery orbit); schedule – initial human flight; extensibility to support Modified Flex Path Missions.

Provide a recommendation for the weighting of the recommended key decision attributes.
Identify how changes to the weighting of key decision attributes affect the architectures.

Identify how alternative ground rules and assumptions (Reference NASA HLLV Study) impact the identified alternative system solutions. For example, due to time and resource constraints, the NASA HLLV study could not address system alternatives associated with the number of launches, alternative LOX/RP 1st stage main engine characteristics, evolutionary vehicle development, the use of propellant transfer or depot, the incorporation of international partner participation, the use of multiple crew spacecraft options, and the effect of technology development.

Identify how innovative or non-traditional processes or technologies can be applied to the heavy lift systems to dramatically improve its affordability and sustainability.

Identify how aspects of a heavy lift system (including stages, subsystems, and major components) could have commonality with other user applications, including NASA, DoD, commercial, and international partners.

Identify how incremental development testing, including ground and flight testing, of heavy lift system elements can enhance the heavy lift system development.

Identify capability gaps associated with the Heavy Lift System, and for each capability gap identify specific areas where technology development may be needed. Items identified as requiring technology development shall be quantitatively evaluated using established metrics, i.e. NASA Technology Readiness Level (TRL), Capability Readiness Level (CRL), Manufacturing Readiness Level (MRL), Process Readiness Level (PRL), etc.

Identify capability gaps associated with the first-stage main engine functional performance and programmatic characteristics required to support each Heavy Lift System studied. The minimum set of functional performance characteristics identified shall include engine thrust, specific impulse (Isp), mixture ratio, mass, throttle range, and physical envelope. This assessment shall include, but is not limited to, LOX/RP main engine systems. The minimum set of programmatic characteristics identified shall include an estimated overall lifecycle cost (DDT&E and recurring per engine cost), development schedule, and production rate. Identify any impacts to overall life cycle costs of the heavy lift system based on the engine studied.

Identify capability gaps associated with the upper-stage main engine functional performance and programmatic characteristics required to support each heavy lift system studied. The minimum set of functional performance characteristics identified shall include engine propellants, thrust, specific impulse (Isp), mixture ratio, mass, throttle range, and physical envelope. The minimum set of programmatic characteristics identified shall include an estimated overall lifecycle cost (DDT&E and recurring per engine cost), development schedule, and production rate. Identify any impacts to overall life cycle costs of the heavy lift system based on the engine studied.

Identify capability gaps associated with all other technical aspects of heavy lift system, i.e. tanks, propellant and pressurization systems, integrated system health management, auxiliary propulsion systems, avionics and control systems, structures, etc. Identify test and integrated demonstrations to mitigate risk associated with the gaps.

Identify capability gaps associated with the in-space space propulsion elements functional performance and programmatic characteristics required to support each Heavy Lift System studied. This assessment shall include, but is not limited to, LOX/H2 and LOX/CH4 propulsion systems. The minimum set of functional performance characteristics identified shall include propellant definition, thrust, specific impulse ($I_{sp}$), mixture ratio, mass, throttle range (if any), and physical envelope. The minimum set of programmatic characteristics identified shall include an estimated overall lifecycle cost (DDT&E and recurring per engine cost), development schedule, and production rate. Identify any impacts to overall life cycle costs of the heavy lift system based on the engines studied.

Identify capability gaps associated with all other technical aspects of the in-space space propulsion element, i.e. tanks, propellant and pressurization systems, cryogenic fluid management, integrated system health management, auxiliary propulsion systems, avionics and control systems, structures, autonomous rendezvous and docking, etc. Identify test and integrated demonstrations to mitigate risk associated with the gaps.

Identify what in-space space propulsion elements, if any, which should be demonstrated via space flight experiments.