**Objectives Before Architectures – Strategies Before Tactics**

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The release of the long-awaited report from the Augustine Commission has generated much discussion in space policy circles. Much of this discussion is congruent with a lot of the debate within the space community in that it focuses primarily on means rather than ends. A more pressing issue is *why* are we going into space with people and *what* will we do there. What are we trying to accomplish? We first need to look at our objectives, not the architecture. We need to develop a strategy to achieve our objectives; the tactics are the ways of implementing a strategy. In other words, once again, we are putting the cart before the horse.

The report lists several options for the future direction of the space program. It largely focuses on the implementation of the next generation spacecraft, the retirement of the Shuttle and use of the newly completed International Space Station, and various aspects of the long-range goals of the program. The report concludes that while a human mission to Mars is the "ultimate destination," other intermediate missions can be envisioned, including a "flexible path" architecture designed to send people to many different destinations, such as Lagrange points and asteroids. Another principal finding of the Augustine report is that NASA does not have a budget sufficient to accomplish its current endeavors. This idea, widely accepted in the space community, is viewed by many as a call to action to work for more money for the agency.

**How Did We Get Here?**

After fifty years of space exploration, many still do not understand or appreciate how profoundly it has improved our lives. Space has benefited humanity with new knowledge and technical capabilities that have great positive impact on many different fields of endeavor. We began our national journey in space in response to geopolitical necessities; we have since discovered that while sufficient to start great journeys of space exploration, such motivations are not sufficient in either time or magnitude to sustain such journeys for the multiple decades needed to make significant progress. Thus, we search for new rationale, different from geopolitics, to make the case for spending public treasure on national space exploration programs.

The reason for space exploration according to the Vision for Space Exploration (VSE) is to serve national scientific, security and economic interests. Traditionally, government space serves the first two aspects well. We have reconnoitered the entire Solar System with our probes and mapped the heavens in unprecedented detail. Our national security assets constantly monitor the globe, feeding us critical information in real time that has increased our security at home and abroad. The last motive – our economic health – has traditionally followed from either technical innovation or new capabilities provided by government space. It has been an unequal, almost forgotten partner in that its impact in this field usually has been secondary and delayed.

Because the Department of Defense has its own space program and infrastructure, NASA has taken leadership in the scientific realm. This circumstance has led to the idea that the civil space program is primarily a tool for the scientific exploration of the universe. Attempts to commercialize space have had some success (e.g., communications satellites), but from a security perspective, in large part, our current space program is a venue for "soft power" projection (e.g., the idea that human space exploration is a Great Power activity and thus, the United States must conduct it.)

The basic difficulties with space is our residence at the bottom of a very deep gravity well (the Earth) and the rocket equation. It takes a lot of energy to get into space and you must drag what you need with you. The rocket equation allows you to do this, but its numbers are daunting: if you can launch a vehicle with a payload fraction larger than a couple of percent of the total mass, you are doing well. To go to the Moon, you not only have to launch the machines and equipment you need there, but all the supporting materials you need as well. For human missions, this includes air, water, food and environmental protection. Add to this the rocket fuel you'll need to accelerate out of Earth orbit, the fuel needed to land on the Moon, along with the fuel you'll need to return to the Earth and the depressing arithmetic quickly sums up to very large masses – and very large costs.

In 2004, President Bush articulated the Vision for Space Exploration, subsequently endorsed by two different Congresses. The VSE emerged after a year-long interagency study to set a new strategic direction for NASA in the wake of the loss of the Shuttle Columbia. Setting such a direction had been attempted many times before, but the net result of such policy directives was usually a frenzy of paper-pushing activity followed by nothing. The Vision was an attempt to go back to first principles: to identify the basic issue with space and attempt to formulate a way to mitigate our main difficulty, the "Tyranny of the Rocket Equation." Learning how to use the material and energy resources of space came forward as a primary mission. It recognized the Moon as the first goal because it is the nearest source of the materials and energy that can be used to create a space faring transportation system. The Vision is not limited to the Moon and Mars; the ultimate objective is to create the ability through the use of space resources to go anywhere and do everything.

A key assumption of the VSE was that no significant increase in NASA's budget was likely, either immediately or for the foreseeable future. Thus, the agency was charged with devising a way to gradually extend human reach beyond low Earth orbit using existing levels of resources. This was (and is) quite a challenge. The key to accomplishing this is to make the free variable *time* rather than *money*. We were to gradually but inexorably "make steady progress, one step at a time." Although dates were given for lunar return, they were intended as guidelines, not deadlines. They represented best estimates for when specific milestones might occur.

Given these conditions, what does it imply for our return to the Moon under the VSE? First, you must understand and accept the nature of the objective. In this case, the

objective was well articulated: We go to the Moon to understand how we might live off the land and use local resources to create new capabilities. Next, we must design a strategy that uses small, incremental steps. Each small mission gives us either strategic knowledge or some capability. Moreover, these steps are cumulative; we obtain more capability with time and the individual steps build upon each other. This is a critical insight; it allows us to make constant progress and not lose our way, even when budgetary times are difficult.

Let there be no misunderstanding. No one knows if the use of space and lunar resources is even possible, let alone whether it can be done "for profit" (defined here as giving you more capability somewhere than you could obtain for equal expenditure of launching the same materials from the surface of the Earth.) It could well be that given the operational difficulties, power requirements, or nature of the lunar surface that using these resources may not be feasible. But it is NASA's task to try and answer this question with both technical detail and financial fidelity. Some claim that use of extraterrestrial resources is fantasy, but all that either side of this debate have are educated guesses. A series of missions designed to actually attempt this and to understand the real technical difficulties and economic breakpoints has never been attempted. A program to attempt this on the Moon is valuable even if we find resource harvesting is not feasible; at least we'll know that we're confined to this world.

The Vision outlined a clear set of objectives in space, but left the implementation of those objectives up to NASA. The first step in implementing the VSE was to name a Presidential panel (the Aldridge Commission), whose report *A Journey to Inspire, Innovate, and Discover* was released five years ago. This report recognized that a sustainable, multi-decadal space effort required both clever implementation as well as strong management to carry it through multiple Congresses and Presidential administrations. The report suggested several ways to accomplish sustainability, including more involvement of the private sector and vigorous technology investment. The Aldridge Report was more a statement of general principles than a roadmap for the agency. NASA still had to decide the details of how to return to the Moon.

The agency made many poor (or at least questionable) decisions in implementing the VSE. From the beginning, an emotional faction within NASA attempted to torque the VSE away from the Moon, pursuing a focus on human missions to Mars. This obsession led to many key architectural decisions that inhibited our ability to develop an incremental lunar strategy. In 2005, the new Administrator Michael Griffin ordered a 90-day, in house effort called the Exploration Systems Architecture Study (ESAS). It was primarily focused on the specific equipment needed to return to the Moon – what rocket launchers to build and use, how big the Crew Exploration vehicle should be, what mission mode to use. The final result of ESAS looked similar to a Mars mission study Griffin had written for The Planetary Society in the first half of 2004. But the ESAS said nothing about the objectives of lunar return or even the activities assumed to be undertaken on the Moon, except to suppose a repeat of Apollo surface exploration. ESAS was focused on creating a transportation system and one solely dependent on launching all assets from the Earth's surface. To this end, the ESAS architecture's key

enabling asset is development of the Ares V launch vehicle, a super-heavy lift rocket that can put 150 metric tonnes (mT) into low Earth orbit (LEO).

The biggest piece missing from the ESAS architecture was an understanding of our objective: *why* we are going to the Moon in the first place. NASA's Exploration Systems Mission Directorate attempted to answer this question in classic "consensus" fashion by having an "inclusive" meeting that brought "the stakeholders" together in Washington for a three-day workshop. They came up with six "themes" to describe possible activities to be undertaken on the Moon. This effort was later augmented by a wider community effort to flesh out these themes, which ultimately resulted in the memorably entitled "Spreadsheet of Death" that laid out 181 specific goals and objectives of lunar return.

With six themes and 181 entries in a spreadsheet, no one at NASA could say in a single sentence what their objective was in going back to the Moon. They still can't, even though it is clearly articulated in the VSE. The Constellation Program is interested only in building their spacecraft and rocket. The scientists spend their time cataloging wish lists into "roadmaps." And no results from these diffuse, unrelated activities are fed into any master plan for lunar return. In short, the solution of maximum entropy has been achieved – all needs addressed, all spreadsheets filled in, all Powerpoint charts completed.

NASA's biggest problem is at the root of why there's a new Augustine Commission in the first place – implementing the ESAS will cost more money than the agency has and more than it is anticipated to receive in the future. This impasse led many to question the path that the agency chose to implement the VSE. So much concern percolated through the political system that a presidential commission was empanelled to address it.

The report of the Augustine Commission reviewing NASA's plans found that in essence, the ESAS architecture could be made to work, but it requires more money than the agency has or is likely to get. Because of this presumed budgetary shortfall, the Commission looked into alternative launch systems, architectures, and even ultimate goals. The report contends that "Mars is the ultimate destination" and that establishing a path to get there from here is of key importance. It lists various launch vehicle and architectural alternatives, including one architecture called "flexible path" that does not develop a lunar lander but instead visits asteroids, the martian moons Phobos or Deimos, and Lagrange points in the Earth-Moon-Sun system.

Although the Augustine Commission report has some good attributes, it also has several shortcomings. Its principal aim seems to be the preservation of a human space program; the issue of what people are to do or where they are to go is made a secondary consideration. The report's excessive focus on launch vehicle alternatives masks confusion over the purpose of human spaceflight. The commission seems to equate exploration and science, declaring that "Mars is the ultimate goal" and that heavy lift booster development has "many scientific applications." In particular, they accept the idea that whatever space program is developed, it must "excite and engage" the American people. This belief follows a long agency tradition that romanticizes the Apollo era as

the “Days of public wonder” when launching men in rockets was exciting and budgets were big.

This latter belief is worth some examination in detail. The idea that space exploration excites and inspires the public is a retroactive reading of a more complex and subtle interaction of the public with NASA during the Apollo era. In fact, at the time of the Apollo 11 mission, polls revealed that most thought the large amount of money spent on going to the Moon was not justified by the benefits received. Interestingly, Gallup has asked whether the American people support the space program or not every year for the last fifty years. Despite the state of the program over the years and its various ups and downs, positive support hovers around 50%, plus or minus 10%. In my mind, this indicates a profound indifference about space on the part of the American people. They neither support it enthusiastically nor do they hate it with a passion. They are, in effect, apathetic about it. This tends to jibe with the observation that almost no one votes on the basis of a candidate’s support for the space program.

NASA has always seen public indifference as a problem. I believe it is a great opportunity. If we are freed from the self-imposed requirement to “excite” people, we are free to carry out the more mundane task of laying the groundwork for a lasting, sustainable infrastructure in space. In other words, space ceases to be a modern gladiatorial contest and becomes instead a piece of our economic infrastructure, available for use by many different parties and not restricted to only scientists and cold warriors. An analogy might be with railroads. Most people couldn’t care less about railroads. Yes, they are aware that they exist and many people will read and know about the latest derailment disaster. But they don’t think about them unless circumstance compels them to. Yet for all this, most recognize the importance of railroads to our lives, our well being, and our economy. Railroads even have buffs, that live, sleep and eat their favorite subject and its lore. So does space exploration. The difference is that railroad buffs know that their obsession is uncommon and is not necessarily shared by the general public.

The simple fact is that while many dearly love space travel, others are turned off by the very idea. Yet this does not mean that we cannot explore and use space; it only means that its rationale and basis should strive for something more substantial than public excitement. For any taxpayer program to be sustainable over years and decades, it must return tangible benefits to the American public. And there is no reason not to set out a strategy towards that objective. We can make space part of our economic sphere of activities; indeed, this is the exact phrase used by Dr. John Marburger, one of the architects of the VSE, in several speeches on space and to the Augustine Commission. The idea that NASA needs to excite the public with a big space spectacle misreads history (Apollo never had that), misunderstands the present (most of the public doesn’t follow space), and does not comprehend the future (we need to develop a true space transportation infrastructure; railroad building doesn’t excite people.) NASA’s constant attempt to become an exciting entertainment venue, rather than the technological R&D entity it should be, has resulted in fifty years of spinning our wheels in space.

**What We Should Be Doing**

So if everyone is missing the point, what would I do differently? First, I believe there is a path forward but that it requires some new ways of thinking about the problem of space and what we are doing there. Second, we should assume that it is unlikely that NASA will get significant new money, either now or in the future; frankly, its performance over the last five years has not produced any indication that new money would be spent wisely. Third, define objectives before the architecture, and strategy before tactics. The biggest waste of time over the past five years has come from designing an architecture that supposedly satisfies any conceivable desire or mission; it resulted in an unaffordable, unsustainable, unusable architecture, not to mention spawning a complete top-down, outside review of the agency's activities.

Our objectives in space are to go anywhere at any time, with whatever capabilities we need to do any job that we want. Admittedly, we are a long way from such capability. The first step towards it is to learn how to create a sustainable human presence off the Earth. I use "sustainable" in both senses here – sustained space presence and capability by people and machines and a sustained space program, returning benefit for expenditure. Our objective is to learn to create new capabilities to explore and use space from what we find in space. In other words, we are to locate, access, process and use the material and energy resources of space.

The Moon is the first step because: 1) it has the material and energy resources we need to build a lasting and extensible space transportation system; and 2) it is the closest, most accessible locale beyond LEO with such attributes. A cislunar transport system can access not only the Moon, but also every other point in cislunar space, where all of our assets – security, economic, and most scientific – reside. Routine access to these satellites and sensor platforms will revolutionize the spaceflight paradigm from one-off satellites, launched on expendable rockets and then abandoned when worn out, to the development and use of maintainable, upgradeable, and extensible systems. The creation of this space transportation infrastructure can be scaled to needs and available resources. Time, not money, is the free variable.

The architecture to create such a system must be designed so that progress is made regardless of budget levels. This implies small, incremental steps that build capability with time. It also implies a different way of conducting business; use of commercial launch services in the human program should be pursued whenever possible, just as the agency does now with robotic probes and satellites. Along with existing launch vehicle families such as Delta and Atlas, new space companies are readying the next generation of launch vehicles that will offer routine and cost effective access to low Earth orbit. This leaves NASA free to develop vehicles to take people beyond LEO and to work on the technologies needed to conduct the lunar surface activities.

The mission on the Moon is to learn the skills and to develop the technologies needed to productively live and work on another world. This long-term goal is approached incrementally. Significant progress can be achieved with robotic spacecraft and

teleoperations. Much of what we need to know about the Moon and what we need to do once we get there can be done before people arrive. We need to survey possible resource prospects on the Moon, test and demonstrate various feedstock collection and resource processing techniques to optimize the process we choose. Much work and study has already been done toward these goals. Finally, robotic machines on the Moon can prepare an outpost site, construct key elements like power systems, landing pads, and roads, and emplace habitats and laboratory facilities such that when people arrive, they can begin productive work immediately. Because of the Moon's proximity, teleoperation of these robotic assets is possible with near instantaneous radio communication.

This basic architectural framework allows considerable flexibility in determining the systems and pieces to be developed and used. Launch vehicles should be chosen strictly on the basis of availability, utility and cost. The need for a heavy lift vehicle (~100 mT) has never been proven; it is only a bias of the previous architects. If a Shuttle-derived heavy lift is easily and cheaply done, it should be used. If not, scrap it. Existing EELV can put about 25 mT in LEO; through the use of such features as propellant depots, a lunar return architecture could be designed around these launch vehicles. Rockets should be the means, not the ends of space faring. Our quest is to free ourselves from their more onerous constraints as quickly as possible.

The International Space Station (ISS) is an asset whose potential for creating space faring infrastructure remains unrealized. In addition to its possible use as a staging node to points beyond LEO, it could become a technology test-bed, allowing us to obtain valuable experience with a variety of technologies essential for sustainable spaceflight. Much of this research involves understanding the issues and mitigating the problems of handling and using cryogenic liquids in microgravity. We will make rocket propellant on the Moon. These are skills that we must master to become a space faring species. On the ISS, we can experiment with cracking water into hydrogen and oxygen, liquefying the gases, storing and transferring them, and even using this propellant to maintain the ISS orbit. Handling and storing rocket fuel is critical to using space resources for creating new capabilities. Learning these tasks on the ISS makes strategic use of that unique facility.

A lunar return architecture can be envisioned that uses the ISS as an assembling and staging area. Cargo can be transported out of LEO using efficient but slow, solar electric propulsion to the Earth-Moon Lagrange point, either L1 or L2, depending upon the trade studies. Crew can follow in faster, chemical rocket transports. At least two different sized landers should be developed. A small, 1-2 mT class cryogenic lander can deliver robotic rovers, surveyors, and resource demonstration landers. After outpost establishment, it can be used in the same manner as the Russian *Progress* spacecraft are now used to resupply ISS. It can also deliver science payloads around the Moon after being re-fueled with lunar propellant. For human missions, a permanent, reusable lunar lander should be developed. It need not be a 50 mT behemoth; a smaller 20-30 mT lander would suffice. Its only purpose is to transport humans and high-value cargo down to the lunar outpost and back. Initially it will be fueled from the depot established at the L1 staging node; ultimately, we want to fuel it with lunar-produced propellant.

On the Moon, we will learn how to live off-planet. This involves establishing habitats that are safe from the extreme thermal and radiation conditions. The poles of the Moon are promising locations for habitation, with their near-permanent sunlight for power production, benign thermal environment with near-constant temperatures, and deposits of volatile substances in permanently shadowed crater floors. It means producing consumables such as air and water from lunar materials. It involves studying and exploring the new world to gain strategic knowledge and to practice for future missions to other planets. Learning how to process resources is the main goal, first for local consumption but ultimately for export to cislunar space. Most of this work is done robotically, but people are needed to maintain the robotic equipment, to conduct detailed work to improve processing techniques and yields, and to supervise the robotic activities. Undertaking such work explores the real trade space of the "human-machine partnership."

Establishing a presence on the Moon is only the first step to extending human reach beyond the Earth. We go to the Moon to create a cislunar transportation system that allows us routine access to not only that zone, but beyond. After lunar operations are established and running, NASA should transition these facilities to the private sector for extension, refinement and commercial operations. Lunar-produced fuel should be used for missions into deep space, first to the Earth-Moon Lagrange points and asteroids, then to Mars and other planets. Asteroids in particular are key destinations; they contain material resources that can greatly extend and augment our space faring capabilities. Launching a human mission to Mars with all of its required rocket fuel brought up from Earth requires a vessel with a mass of over one million pounds in LEO. Launching such a mission would take at least 8-12 heavy lift launch vehicles. In contrast, a spacecraft to Mars using propellant made on the Moon would have an Earth-launched mass of only about one-fifth that amount (100 mT; 1-2 heavy lift launches) and could be fueled at and depart from the Earth-Moon L1 staging node.

**Conclusions**

Currently, we are going nowhere in space. Five-and-a-half years after the Vision for Space Exploration was announced there is still confusion about what it is – why we would go back to the Moon and what activities should be undertaken there. The existing architecture is unsustainable, with vehicles designed for missions whose objectives are unknown. There is no need for such confusion; the VSE was thought out carefully and articulated clearly. It has simply been ignored.

Budgets for space are projected to be flat at best for the foreseeable future. Nevertheless, at around $20 billion per year, NASA is hardly broke. More money does not necessarily translate into a better product. The real issue is how you spend that money and how you construct a sustainable program around such a sum.

Arguments raging in the space community about rockets and destinations miss the point. A clear *mission* is needed. The VSE gave NASA a mission, an objective and a strategy

as clear and direct as any since John Kennedy's formulation, "Man, Moon, Decade." The VSE replaced the schedule-driven Apollo-type paradigm with one constructed around building capabilities incrementally, of "making steady progress, one mission, one voyage, one landing at a time."

To break the tyranny of the rocket equation – the budget-breaking need to bring everything out of our deep gravity well – we must learn to use what's already in space to create what we need. To accomplish this in a constrained fiscal environment, we need to build a program using small, incremental, cumulative steps. Considerable capability can be developed over time, even under tightly constrained budgets. We seek to create a lasting access and transportation infrastructure that is predominantly *space-based*, rather than Earth-based.

We have a choice. We can either grab the problem with both hands and learn to use space resources to build new and lasting capabilities or we can continue to do what we've done for the last fifty years. If space remains the preferred playground of academics and bureaucrats, they will be the ones to determine where we go and what we do. Make no mistake – many would be happy forever with the existing paradigm. They will limit activities in space to only those things they deem important. They will consume wealth rather than create it. In contrast, a space faring transportation infrastructure that uses what awaits us in space is both extensible and enabling. It permits many different people with varying needs and objectives to get to a variety of space destinations and conduct a range of activities there. It opens the frontier of space to economic growth as the transcontinental railroad opened up the American west.

We don't think too much about railroads today. We should. They have a lot to teach us.

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