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COMPARING FUTURE OPTIONS FOR HUMAN SPACE FLIGHT

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The paper analyzes the "value proposition" for government-funded human space flight, a vexing question that persistently dogs efforts to justify its 10^{10}/year expense in the U.S. The original Mercury/Gemini/Apollo value proposition is not valid today. Neither was it the value proposition actually promoted by von Braun, which the post-Apollo 80% of human space flight history has persistently attempted to fulfill. Divergent potential objectives for human space flight are captured in four strategic options—**Explore Mars**; accelerate **Space Passenger Travel**; enable **Space Power for Earth**; and **Settle the Moon**—which are then analyzed for their Purpose, societal Myth, Legacy benefits, core Needs, and result as measured by the number and type of humans they would fly in space. This simple framework is proposed as a way to support productive dialogue with public and other stakeholders, to determine a sustainable value proposition for human space flight.

I. INTRODUCTION

> The future is highly unpredictable. Creative, adaptive behavior that is based on value has more value than goal- or mission-directed behavior, which is always based to some extent on historical analysis. History is going to be of less use to us in the future.
>
> - J. Rohde, VP/Creative, Disney Imagineering[1]

Civilization uses governments to accomplish what no individual, corporation, or consortium can afford. All government ideas, plans, investments, and projects for human space flight (HSF) can and eventually are judged against their fundamental value proposition. Passing this judgment requires HSF programs to know clearly what their value proposition is. Given events of the past four decades, and cyclical replanning, reasonable questions in 2010 are: What *is* the value proposition for government investment in HSF?[2] And what should it be?

This paper explores these questions, seeking answers deeper and less vague than "destiny" or "technological innovation" or "the drive to explore." It finds just four alternative value propositions for government investment in human presence beyond the International Space Station (ISS). These four options are startlingly different. They are easy to explain to ordinary people, which makes them useful for probing public interest and commitment. They would be an easy "litmus test" of relevance for proposed priorities and projects. Interestingly, the option pursued by the U.S. HSF program has not fundamentally changed from the time of von Braun, despite numerous changes in societal context, leadership, technology, or risk tolerance. Stepping back to compare the four options may be appropriate for the challenges of our time and our shared desire for more HSF progress.

II. VALUE PROPOSITIONS YESTERDAY AND TODAY

A very terrestrial value proposition—proving global technological dominance—propelled the first decade of government-funded HSF, as is well understood. However, upon its fruition (first with the Apollo Moon landings of 1969–72, and ultimately with the Soviet Union's dissolution 20 years later) there was no further value to be extracted from this proposition.

NASA's last major project (ISS) took a quarter century to complete—ten times the typical job tenure of today's graduates. Although the public remains vaguely proud of NASA, people have no idea what human space flight costs or how this compares to other government programs. They cannot name astronauts or what their missions do. And they can't explain any connection between HSF and their quotidian problems. What might today's HSF value proposition be?

The last four decades of HSF have appeared to be about "laboratories in space," progressing from *Skylab* and *Salyut* to *Mir* and culminating in the ISS. Three sociological points provide important clues for understanding how HSF is viewed by our society today. First is the reduced pace of this period compared to the Apollo era—four decades rather than one—caused by absence of national urgency and technical challenge we discovered along the way. This factor-of-four time dilation requires a sustainment of public attention that conflicts with the decreasing attention span of today's stakeholders. Second is that the astounding achievement of ISS is sometimes derided as "going in circles" and thus somehow intrinsically not worthy because it is not "exploring" a frontier. Evidently fundamental research and learning are less interesting than pressing outward. Third, likely because of the time dilation, neither the Shuttle nor Freedom/ISS were recognizable to the public for what they actually were: elements gradually implementing the three-step HSF blueprint laid out by

von Braun in the 1950s: reusable space shuttle, orbiting space station, humans to Mars.[3,4] Over four decades the public "lost lock" on the grand plan.

Nonetheless, **Explore Mars** has always been the implicit value proposition of U.S. human space flight. It pre-dated Kennedy's superposition of the geopolitical value proposition that got Apollo to the Moon, biding its time during that era and then riding Apollo's momentum up to this point.

And it is still our value proposition. The Space Exploration Initiative announced in July of 1989 put the U.S. on a path "back to the Moon, this time to stay, and then [on] to Mars."[5] Despite inadequate funds to do more than "go in circles" anyway, debate simmered about whether our next "destination" should be Mars or the Moon. Earnest factions competed to promote nuclear technologies, "Mars Direct," *in situ* resource utilization, astronomy from the lunar surface, outpost vs. sortie, and so forth.[6] Fifteen years later, the Vision for Space Exploration announced in January of 2004 established priorities by proffering the Moon as an affordable stepping-stone to Mars.[7,8,9] However, the U.S. declined to afford that strategy also. After a change in presidential administration, the Future of U.S. Human Space Flight Plans Committee (aka Augustine Committee) proposed a "Flexible Path" strategy to extend human presence into deep space "with no immediate plans for planet surface exploration," yet at the same time reasserting Mars as the "ultimate destination" for HSF.[10] The Obama Administration embodied this approach in budget proposals, and the President himself challenged NASA on April 15, 2010, to launch a first human mission to an asteroid by 2025, and reach Mars orbit in the mid-2030s. NASA's Human Exploration Framework Team calls Mars the "horizon destination" for HSF.

Apparently **Explore Mars** is a refractory meme: fired in von Braun's own crucible, it has outlasted a half-century of world history, eleven U.S. Presidents, 25 U.S. Congresses and 50 NASA budget cycles, three generations of aerospace professionals, Apollo and two other attempts to compromise on the Moon, and the ascendancy of robotic exploration which has replaced romantic visions of an inhabited Mars with the real possibility that Mars may once have harbored microbial life. That humans could—and someday will—**Explore Mars** has become a full-fledged modern myth.

III. MYTHS AND SOCIETAL MOTIVATION

Betty Sue Flowers, poet and former Shell Oil executive, speaks about how societal "myths" apply to the HSF enterprise.[11] She defines myths as stories "that create meaningful reality," stories we use to organize and prioritize values and experiences, stories so embedded into society's core that they are deeply, widely, and instantly understandable. Myths are continually reinforced by reference: in stereotypes, humor, the media, and innumerable other outlets. She describes three "myths that made us:" *Hero*, *Religious*, and *Democratic/Scientific*; and finds that the modern developed world exists in an *Economic* myth that "maximizes advantage" by using numbers to measure the "bottom line." Finally, she posits a new, inchoate myth: *Ecological*, in which individuals contribute to a networked whole.

Flowers implies that to succeed in the constant competition for public favor, HSF must know which myths it means to embody, and intentionally utilize resonance with myths to win society's support. "When you don't know what myth people are in when they're telling their individual story, you don't really know what's going on." If HSF were to live "between" myths (Hero? Economic?), or be about one myth (Scientific?) but attempt to communicate through another (Economic?), its value proposition would be confusing, defocused, even self-contradictory, and not widely compelling, and it would fail. The key measure of failure would be declining societal relevance, then political will and eventually funding. History demonstrates that when society turns its attention and commitment elsewhere, the cathedral remains unfinished.

Are signs of failure upon us? As Bob Rogers observes, NASA worked hard to make orbital space flight appear routine, an outcome which undercut its original Hero myth and then led to damaged public trust after *Challenger* and *Columbia* demonstrated that it is not yet routine.[12] Now even most space professionals cannot name the crew currently onboard ISS; although they are heroes in the sense of facing personal danger to achieve important things on behalf of society, they no longer live in society's Hero myth.

And what about the important things they are doing? Again, even most space professionals cannot name the litany of research investigations currently underway on ISS. In the mid-20th century scientists were also heroes—elite warriors safeguarding freedom and improving our quality of life. Now white-coated scientists are Gary Larson caricatures seen as Cassandras or used as agents of the Economic myth, rather than being revered as society's truth-seekers.

What does today's society expect from HSF? What does it need HSF to be and do? Can—should—astronauts be Heroes anymore? If society is living in the Economic myth, what value might it ultimately afford an HSF program based in the Science myth?

IV. OPTIONS FOR HUMAN SPACE FLIGHT

Many possible HSF futures have been envisioned over the past half century: activities loosely called "exploration," various commercial enterprises, planetary construction, grandiose mining colonies, even multi-

generational interstellar voyages. Deconstructing and abstracting them leads to just a few basic options useful for comparative analysis.

Table 1 captures these options in four ambitious potential "missions" for government HSF investment in the first half of the 21st century. To first order the four options could be made roughly equivalent in technical feasibility and cost. They share key characteristics: epochal achievements; large roles for existing aerospace constituencies; advanced technology and inspiration for STEM education; international cooperation and use of ISS as a space testbed; and preparation for even greater spacefaring accomplishments in the second half of the century. Each could be done, but they generate very different future states for the coming generations.[13]

The table columns examine comparable facets for the four options. Each option is stated first as a "sound bite" verb phrase, then (in the second column) elaborated into the rationale a nation might articulate for pursuing it. The third column indicates a core "myth" it embodies, in the sense defined above. The fourth column summarizes the option's expected legacy; these would add to the "bottom line" benefit viewed through the Economic myth and set the foundation for subsequent spacefaring achievements. The fifth column summarizes what the option would need in order to deliver those benefits; these would be its "costs" beyond the $\$10^{10}$/yr of U.S. government HSF investment. The final column predictively assesses a metric that, while novel, seems appropriate for human space flight: the number and

Table 1. Four options for government-funded HSF lead to divergent alternative futures.

Option	Core Purpose	Core Myth	Legacy	Core Needs	Space Population Enabled by 2040
Explore Mars	• Extend direct human experience to the most remote destinations feasible • Understand past and future potential of Mars to support life	**Hero** (Lewis and Clark)	• Life elsewhere? • International interdependence • NEOs as stepping stones to Mars • Highly reliable space systems	• Advanced propulsion • Deep-space human systems • Public commitment sustained over decades • International co-investment	Six international government employees on a distant planet
Accelerate space passenger travel	• Open space to citizens • Create new travel-related industries • Extend LEO-experience perceptual shift to large population	**Jet set** (Branson)	• Highly reliable, reusable Earth-to-orbit systems • Space hotels and resort destinations • Routine in-space service industries (e.g., food, maintenance, medical) • 1-hr intercontinental travel	• "Four 9s" launch reliability • Reusable launch • Public-private partnerships • Commercial crew corps	10^3 crew + 10^5 citizens per year visiting low Earth orbit
Enable space solar power for Earth	• Prepare for post-petroleum age with minimal disruption • Create new energy-related industries • Become global exporter of unlimited clean energy	**Green**	• Heavy-lift launch • Routine in-space high-tech industries (e.g., construction, robotics) • Changed land-use patterns • Culture shift to use space resources	• Power beaming safety regime • Inter-Agency partnerships • Public-private partnerships • Commercial space worker corps	10^2 skilled workers on extended duty tours in high Earth orbit
Settle the Moon	• Establish humanity as a two-planet species	**Pioneer** (Heinlein)	• Permanent human presence offworld • Lunar industries (high-tech and service) • "Living off the land" in space • Offworld import/export • Lunar tourism	• Routine heavy traffic to lunar surface • Public-private partnerships • ISRU • Full suite of technical skills and social services	10^3 mixed-demographic citizens offworld, some permanent and raising families

nature of humans that the option would actually fly in space.

Option 1: Explore Mars

The first option is the familiar meme discussed above: **Explore Mars**. Reduced to its essence, the core purpose of humans exploring Mars is twofold: extend human presence to the farthest planet feasible; and understand Mars habitability. Through robots, humans are already exploring Mars and gaining tremendous understanding; but direct, physical human experience addresses an urge beyond science. Additionally, one area—the many possibilities for life at Mars—is widely compelling and appears to require a depth of investigation beyond what we anticipate being able to do with remote machines. Many aspects place the **Explore Mars** option squarely in the Hero myth: unprecedented goal that becomes the stuff of legend; remote environment full of lethal risks both known and unknown; tiny band of intrepid humans at the "tip of the spear" of a massive human endeavor; direct parallels with Apollo. An HSF program intending to **Explore Mars** should actively embody and promote the Hero myth.

The expected legacy of the **Explore Mars** option is surely epochal: (1) settling the persistent question about life on Mars; (2) deepening the peaceful, technological international interdependence that ISS began; (3) visiting asteroids and learning how to prevent future impact catastrophes; and (4) developing systems of systems that can reliably support human life very far from Earth. To deliver this legacy, the **Explore Mars** option needs: (1) significant advances in space propulsion and human space systems; (2) sustainment of public emotional and financial will over a "cathedral-building" attention span rare in 21st century; and (3) that commitment spanning the globe because even the richest nation on Earth cannot afford the $\$10^{11}$ cost alone.

The culmination of this option would be a half-dozen or so civil servants reaching, exploring, and returning safely from a point of light in the night sky. To be fair, similar crews would have reached out earlier—beyond the geomagnetic field, to near-Earth objects (NEOs), perhaps to Phobos in Mars orbit—to build confidence for the first Mars excursion. And other crews would subsequently explore Mars to fulfill the purpose of understanding Mars habitability. Indeed such a mission series touches a Hero-derivative myth deeply resonant with Americans: Lewis and Clark, gutsy explorers sent by their President on a mission to map new territory. But the defining historical moment, media image, and headline of the **Explore Mars** option, as with its progenitor Apollo, would be the first small, international crew: "Humans on Mars."

Option 2: Accelerate Space Passenger Travel

The second option is quite different: **Space Passenger Travel**. This option does not mean governments flying passengers in space; rather it means focusing government HSF investment to develop technologies and remove barriers to accelerate the success and growth of a new, commercial space passenger travel industry. The precedent is NASA's own predecessor the N.A.C.A., the National Advisory Committee for Aeronautics founded in 1915. Formed as an urgent war-time effort, the N.A.C.A. went on to conduct the fundamental airfoil and other research that still underpins today's commercial jet industry and modern supersonic fighters.

The core purpose of the **Space Passenger Travel** option would be to open space travel to ordinary people, thereby creating new travel-related industries to conduct and support it. Another expected outcome would be exposing large numbers of people to the Overview Effect: a perceptual shift documented to happen to space travelers, which deepens their appreciation for the unitary, fragile nature of Earth.[14] The Overview Effect is hypothesized to be caused by looking at Earth "from outside" while experiencing the detached sensation of microgravity. It tends to sensitize travelers to the planetary impacts of human territoriality and environmental destruction, and to deepen spiritual convictions. It is conceivable that large numbers of people experiencing this shift could begin to affect societal views through media and other meme-spreading communications. Such an outcome would be a legacy in the fourth column if unintended, or a "purpose" in the second column if used as a rationale. Increasingly affordable and accessible space travel could be a transformational contribution to humankind's 21st century, more real than watching astronauts on TV.

The core myth for this HSF option is the "Jet Set," a theme arising in the mid-20th century that connotes the freedom, privilege, and transnational detachment of global travel embodied today by celebrity-entrepreneurs like Richard Branson. While triggered by the commercial jet travel enabled by WW-II technology, the Jet Set myth has roots as far back as the early-20th century Art Deco and International Style industrial design and architecture movements, which grew in response to early aviation speeds and materials. For a new myth it is remarkably pervasive: *The Jetsons*, a middle-class American family animated into a world of robots, flying cars, and lunar vacations, and the Orbiter Hilton in *2001: A Space Odyssey* depict instantly recognizable, resonant examples from the 1960s. Jet-setters, and the vast populations who admire and emulate them, tend to imagine that flying into Earth orbit, or to the Moon, is something they will be able to do someday, and this aspiration makes the myth. An HSF program focused on accelerating **Space Passenger**

Travel would actively, consciously promote the Jet Set myth.

We know this HSF option is real because, even without significant government attention, sub-orbital tourism and orbital habitat development have attracted private investment. Against all odds, some entrepreneurs —Bigelow, Rutan, Branson, Musk, and others—are creating a fledgling space tourism industry. And there probably is a business case. A trip that couples the ride of your life with the unique sensations of weightlessness and the most poignant, ever-changing view in the solar system fits our contemporary "experience economy." Former NASA Administrator Dan Goldin used to pound on the podium and declare, "Space tourism is not my job!" But there is no fundamental reason why it couldn't be; NASA's HSF charter could be directed to accelerate **Space Passenger Travel**.

The expected legacy of this HSF option would be as epochal as Explore Mars, but in quite different ways: (1) routine flights between Earth and orbit on competing spaceship fleets; (2) in-space destinations with accommodations likely ranging from budget-utilitarian to high-end resort; (3) in-space service industries including dining, shopping, recreation and entertainment, medical care, and maintenance. (4) Government space professionals would travel into orbit along with private passengers as they do today on commercial jets, and stay at commercial hotels while they work in orbit. (5) Another orbital passenger travel legacy (or again, it could be a driving purpose) would be half-orbit intercontinental travel, e.g., London-to-Sydney in less than an hour.

But to accomplish this, the **Space Passenger Travel** option needs several breakthroughs exceeding the capacity of private enterprise without government help. (1) Earth-to-orbit transportation would have to be fully reusable for the commercial business case, and be reliable far beyond anything achieved so far by the world's space programs. Paying passengers are not heroes; risk would only be acceptable in the same way it already is for air travel, e.g., with "four nines" or greater reliability. (2) A variety of unprecedented space-system technologies could become essential: large-volume habitats, very large windows, berthing mechanisms capable of thousands of cycles, fresh food production, air and solid-waste life-support loop closure, space surgery, rotating artificial gravity, sports and public entertainment. (3) Targeting government research toward accelerating this new industry would require public-private partnerships like research consortia, port authorities, and company towns. (4) And not least, the long-term radiation health of commercial crew corps and space workers would need to be managed, and they would need certification.

At a reasonable state of maturity (after 30 years of cumulative public-private investment?) the **Space Passenger Travel** option could achieve a continuous throughput of hundreds of thousands of citizens flying in space per year, supported by thousands of professional crew and in-space workers (at typical terrestrial ratios, the latter would reach tens of thousands). Its historical significance would be more subtle than the Explore Mars option: rather than historical headlines, an imperceptible but irreversible societal evolution.

Option 3: Enable Space Solar Power for Earth

The third option is yet again different: **Space Power for Earth**. As with Space Passenger Travel, this does not mean governments building power plants in space and beaming energy to Earth. Rather it means focusing government HSF investment on developing technologies and removing barriers so public-private partnerships can successfully build and operate space-based power utilities. The technical concept is well-known: large geosynchronous satellites would convert uninterrupted sunlight into electricity, then transmit microwave power to large rectenna farms on Earth for reconversion into electricity for the grid.

The core purpose of **Space Power for Earth** would be to sustain the modern appetite for energy while transitioning to a post-petroleum era with minimal disruption to societal norms and infrastructure. Space solar power has not appeared cost-effective so far, but fossil fuels become more expensive the closer we look and the longer we wait. Human society is near "peak oil" and alternatives are unpalatable in various ways: natural gas contributes to global warming; coal does the same and burns "dirty"; fission power yields long-lived radioactive waste and carries non-proliferation risks; fusion power is an undemonstrated hope; and "renewable" sources are localized and insufficient. These defects lead to a final, really unpalatable alternative: dramatic restructuring of civilization to tolerate energy consumption far below current levels. Beamed power from space has the potential to be an inexhaustible, unlimited, and clean source to supplant terrestrial methods, but it cannot be developed or sustained without human space flight.

A secondary core purpose of this HSF option would be to create new energy-related industries organized around mass-production of photovoltaic and solar-thermal converters, microwave or laser transmitters and receivers, and a "smart grid." Another purpose (or legacy, again depending on whether it is intentional) would be for nations that develop the space-based capability to become global energy exporters. Using space-sourced electricity on the ground requires receiver areas within or transmission lines across a country's borders, but producers transmitting from space can easily be transnational. **Space Power for Earth** would enable spacefaring nations to quickly become major,

long-term, energy producers and exporters, yielding a phase change in the geopolitics of energy.

The core myth tapped by **Space Power for Earth** is: Green. Green is even newer than Jet Set; it emerged from the environmental movement of the 1960s, catalyzed by Rachel Carson's *Silent Spring* in 1962, cultivated by widespread media coverage of pollution throughout that decade, and crystallized by Apollo 8's iconic 1968 photograph of Earth rising over the Moon's limb.[15] As the many costs of a growing global population—especially as it aspires to western living standards—have become inescapably clear, the Green myth has become morally central in the developed world and is now even becoming convolved with the Economic myth.

We know this HSF option could support a wider public policy. The contemporary context includes the Obama Administration's July 2010 direction to U.S. federal agencies about science and technology priorities:[16]

> Agencies should pursue transformational solutions to the Nation's practical challenges, and budget submissions should therefore explain how agencies will support long-term, visionary…high-risk, high-return (or "potentially transformative") research.
>
> *[Excerpted from Six Challenges]*
> (1) Promoting sustainable economic growth and job creation. (2) Moving toward a clean energy future to reduce dependence on energy imports while curbing greenhouse gas emissions. (3) Understanding, adapting to, and mitigating the impacts of global climate change.
>
> *[Excerpted from Six Cross-Cutting Areas]*
> (5) Capabilities in space, which are germane not only to looking and exploring outward but also to Earth observation, geopositioning, communication, and more.

There is no fundamental reason why NASA's HSF charter could not be directed to enable **Space Power for Earth**.

The legacy would again be epochal, in this case directly benefiting the Earth and all humanity: clean, inexhaustible power. But it would do more. It would: (1) create new industries, in the process giving us (2) high power in space, (3) affordable heavy lift launch, (3) routine construction and reliable operation of very large orbital platforms, and (4) a deep foundation of peaceful international cooperation.

To meet the core purpose, large numbers of kilometer-scale satellites would be constructed in high Earth orbit, requiring unprecedented flight rates boosting an unprecedented amount of hardware into space. While passenger-level launch reliability would not be needed, minimal launch cost and effluent would be essential. Routine in-space construction and maintenance would be needed, in turn requiring support services for significant numbers of in-space workers: dormitories, cafeterias, and commissaries (or their commercial equivalents), hospitals, and personal services. On Earth, significantly changed land-use patterns would occur, although rectennas for microwave conversion are sparse metallic structures compatible with other large-scale land uses like agriculture.

An implicit legacy would be a culture shift toward reliance on space resources; whether this might lead to more complex uses like mining platinum-group metals from the Moon or from metallic asteroids is speculative but consistent with this option. (Strip-mining the Moon for ^{3}He has been discussed extensively, but no ^{3}He fusion-based power plant has yet been demonstrated, and space solar power would be a less complex enterprise.) The fundamental societal shift would be recognition that Earth is not a closed system, and that a post-petroleum future need not send civilization into a Dark Ages.

Achieving **Space Power for Earth** would require fewer major technological advances than the other HSF options. All systems including launch, construction, habitation, orbit transfer, space platforms, power collection and conversion, inspection and maintenance, and transmission and receiving could be based on known approaches, although significant engineering development would be required and all these areas would undoubtedly benefit from government investment to optimize them. The core need would be (1) an economic development that is inevitable anyway: for petroleum to continue increasing in price and cost until the space-based approach becomes economically favorable. (2) Launch vehicle reusability would be an important but second-order economic tradeoff. Other core needs would include: (3) a regulatory regime for safe transmission of large amounts of power to Earth's surface, including appropriate land-use and airspace controls; (4) interdependence among multiple government agencies (e.g., NASA, EPA, and the departments of Energy, Interior, State, Agriculture, and Defense) to collaborate toward the core purpose; (5) public-private partnerships to finance, develop, and operate a large-scale space-power utility; and (6) a private space-worker corps supported by the requisite in-space services.

The space-based infrastructure would be enormous. Currently humans use about 15 TW of power; meeting that need with power collected and beamed from space, considering end-to-end system efficiencies, would require of order 500 space platforms, each 20 km^2 in area. During construction there would be hundreds, perhaps thousands of skilled workers living in space on

extended duty tours. Creating a **Space Power for Earth** industry would take mega-engineering on the scale of bold programs like construction of the U.S. Interstate Highway System, or Project Apollo. Explore Mars would likely be far harder.

Option 4: Settle the Moon

The fourth option, **Settle the Moon**, may at first appear similar to Explore Mars. As fueled by movies and other media, it can seem to the public consciousness like a natural outcome of NASA human space exploration, vaguely equivalent to, if not merely a side-effect of, aiming for Mars. But this option leads to a quite different future. Its core purpose is to establish humanity as a two-planet species, and its core myth is the Pioneer. Hero Explorers and Pioneers are not the same; the former embrace—perhaps even thrive on—the risk of the unknown, and press outward the limits of human experience, while the latter accept a high but fairly well-bounded risk environment in order to establish a permanent, growing frontier outpost. In addition, Pioneers are not government-funded. As on Earth, government investments would open the way, developing key technologies to lower risk and cost barriers for subsequent private enterprise.

Both the Hero-Explorer and Pioneer myths resonate strongly with Americans, perhaps because European colonization of the Americas, and the subsequent growth to dominance of the United States, are so recent. But the urge to settle appears atavistic enough in human populations to make sense at some level to almost everyone, even for a place as unearthly as the Moon. Unlike the point of light which is Mars, people everywhere can look up and see the Moon easily, knowing from Apollo that it is only days away, and imagine human settlements there. Robert A. Heinlein's fiction taps directly and powerfully into the Pioneer myth in multiple treatments of lunar settlement.

Settle the Moon would herald milestones more historically notable than Space Passenger Travel, perhaps because the Pioneer myth runs deeper and wider than the Jet Set myth. In addition to its epochal legacy of (1) a permanent human presence offworld, this HSF option would yield a rich space-based legacy: (2) a full suite of high-tech and service industries indigenous to the Moon, to support human activities of all types; (3) demonstration that people really can "live off the land" in space with decreasing support from "home"; and (4) a continuous offworld import/export economy. Lunar settlers would need a continuous "pipeline" of items from Earth for a long time, particularly high-tech products like specialized medicines, electronic components, mechanisms, and reagents. In turn, we might expect lunar products sold back to Earth, e.g., vacuum-glass photonic components, ^{3}He and platinum-group metals, low-gravity entertainment, and novelty items. Unlike Mars, **Settle the Moon** could also (5) support robust exchange of people: immigration from Earth to add to the lunar population; non-permanent duty tours on the Moon for all skill levels from service workers to construction crews to surgeons; educational exchanges for terrestrial and lunar students; and tourists. A lunar settlement would be a high-profile space destination.

Of course, a lot would be required to **Settle the Moon**, beginning with (1) routine, heavy traffic to and from the lunar surface. Unlike European or westward-heading American settlers, lunar settlers would find their destination literally uninhabitable. They would need continuous infusions of capital equipment to build up local capabilities to the point of recovering volatiles from lunar regolith (especially nitrogen for breathing air), constructing safe habitats, and accumulating the confidence to sustain a growing population. Such a pipeline of supplies, skills, and safety net would require "heavy lift" landers, high flight rate, or both, which only government investment could develop. (2) *In situ* resource utilization (ISRU) would be essential to leverage the transportation pipeline and enable settlement growth and enrichment. (3) Public-private partnerships would be needed for collaborative development of enabling technologies as well as provision of some emergency services. Ultimately, **Settle the Moon** would require the fullest suite of technical skills and social services imagined for human space flight, because its "mission" would be to establish a sustainable society in an alien place, discovering along the way what "normal" might mean for those people.

At some snapshot in time (after 30 years of cumulative public-private investment?), **Settle the Moon** could yield a thousand people, of well-mixed demographics, professional skills, and social roles, living on another planet. They would comprise the core of a permanent offworld population, raising families and becoming "natives" of a different world.

V. LEARNING WHAT PEOPLE CARE ABOUT

What is the value proposition for human space flight in today's world, and what might it be 30 years from now? It is not the purpose of this paper to assert value judgments among the four HSF options described above. Instead the purpose is (1) to make clear that there *are* options other than the default path; and (2) to demonstrate that HSF decisions made now—which policy-makers might consider to be roughly interchangeable—lead in fact to extremely different futures. Recall that to first order, all four options could be made to cost the same and be incrementally feasible technically. Understanding the diversity of futures—and particularly space-population end states—enabled by the four options provides a powerful basis for meaningful conversations with stakeholders about what they want most from their human space flight programs.

This approach allows stakeholders to decide which purpose, myth, achievement, investment challenge, or end state resonates best *for them*, and then map it into an HSF option. For example, those motivated most strongly by the Hero myth would likely want to **Explore Mars**; advanced propulsion would then become a key investment. Those motivated by enabling large numbers of space travelers soonest would likely want to accelerate **Space Passenger Travel**; for this, launch reliability approaching airplane-like levels would matter far more than advanced propulsion. Those interested to use HSF directly to solve pressing terrestrial challenges might want to enable **Space Power for Earth**, in which case incentivizing government agencies to work together would become paramount. Those wishing to reignite the Pioneer myth would likely want to **Settle the Moon**, and favor investing in ISRU technologies and scale-up. In every case, the key question is whether that myth, that goal, those benefits, are worth a government investment of $\$10^{10}$/yr. And only the paying stakeholders can answer.

Deriving what a HSF program should be based on sustainable stakeholder vision is novel. Rogers suggests that after Apollo we have been attempting the opposite—first defining our HSF objective and then seeking stakeholder support for it—with unsatisfying results. In fact after Apollo we reverted to the von Braun blueprint, so that our underlying HSF purpose has stayed the same since 1948. Explore Mars remains a powerful myth—and it might be the right HSF option for our society and time—but periodically examining what we think we want appears advisable, particularly after 30 years of "going in circles" and so many failed attempts to rekindle the Hero myth of Apollo.

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