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Decadal opportunities for space architects ☆

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ABSTRACT

A significant challenge for the new field of space architecture is the dearth of project opportunities. Yet every year more young professionals express interest to enter the field. This paper derives projections that bound the number, type, and range of global development opportunities that may be reasonably expected over the next few decades for human space flight (HSF) systems so those interested in the field can benchmark their goals. Four categories of HSF activity are described: human *Exploration* of solar system bodies; human *Servicing* of space-based assets; large-scale development of space *Resources*; and *Breakout* of self-sustaining human societies into the solar system. A progressive sequence of capabilities for each category starts with its earliest feasible missions and leads toward its full expression. The four sequences are compared in scale, distance from Earth, and readiness. Scenarios hybridize the most synergistic features from the four sequences for comparison to status quo, government-funded HSF program plans. Finally qualitative, decadal, order-of-magnitude estimates are derived for system development needs, and hence opportunities for space architects. Government investment towards human planetary exploration is the weakest generator of space architecture work. Conversely, the strongest generator is a combination of three market drivers: (1) commercial passenger travel in low Earth orbit; (2) in parallel, government extension of HSF capability to GEO; both followed by (3) scale-up demonstration of end-to-end solar power satellites in GEO. The rich end of this scale affords space architecture opportunities which are more diverse, complex, large-scale, and sociologically challenging than traditional exploration vehicle cabins and habitats.
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1. Introduction[1]

Work opportunities for space architects over the past three decades have been concentrated in four domains: Phase A of the International Space Station (ISS), technology programs like TransHab, NASA future-mission concepts, and commercial passenger launch startups. NASA's direction has historically dominated, but the trends bear reexamination. This paper describes the array of project opportunities most likely available to space architects through 2040.

The analysis includes all the spacefaring activities that cannot be done without HSF; derives rational sequences that are built from near-term to visionary scale and scope; synthesizes future scenarios by hybridizing the sequences; then compares them for their impact on space architecture opportunities.

The analysis is anchored by four drivers already evident: continuing operation of the ISS, severe NASA outyear budget limitations, increasing difficulty justifying NASA HSF, and nascent commercial space adventure travel.

In prior work [1] the author clarified four options for the purpose of HSF, differentiated as salient by what technology investments they require and by what futures

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[1] *This work was done as a private venture and not in the author's capacity as an employee of the Jet Propulsion Laboratory, California Institute of Technology.*

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they lead to. Listed in order of increasing numbers of spacefarers enabled after a few decades of $\$10^{10}$/year government investment, the four are: *Explore Mars*, enable *Space Solar Power for Earth*, *Settle the Moon*, and accelerate development of commercial *Space Passenger Travel*. Of the four only the first has motivated HSF government investment throughout the six decades of the field, with the ironic exception of 1961–1972 when HSF was driven by a competitive geopolitical agenda.

The present analysis focuses on in-space HSF activities. Again there are four, mapped to the HSF goals as follows: (1) deep-space servicing and construction (cross-cutting application); (2) exploration (Explore Mars); (3) industrial development of resources (Space Solar Power for Earth) and (4) human 'breakout' into space (Space Passenger Travel, and Settle the Moon). From these we can derive potential time-phased project opportunities for space architects.

2. Why HSF

About 10,000 years ago humans began the large-scale engineering of their world by creating the first works we recognize today as architecture. In the last 100 years, just 1% of humanity's engineering history, a few pioneers envisioned realistic ways to get off the Earth, beyond the atmosphere, and away from the pervasive and fundamental experience of weight. The feat was finally achieved only half a century ago, when the world's population was half what it is now.

The space age is part of what makes us modern. In that same half-century we have visited the deepest seafloor trenches, occupied permanent research stations in Antarctica, built vast airports where there was only sea before, made climbing Earth's highest peaks an adventure sport, networked our collective thinking, and begun reshaping our DNA. Step by step we are expanding the domain of human presence and the very nature of what it means to be human.

Space awaits as an incomparable frontier of human experience: with vistas, sensations, opportunities and risks, and resources and places without limit. Consider what human space flight has accomplished in just its first half-century: proved we can survive off Earth; visited the Moon; brought nations together continuously for a decade in the ISS; and renovated the Hubble Space Telescope several times.

Our robots and telescopes reach much farther than we dare imagine we ever could ourselves. As we learn about our planet, solar system, and universe almost out to the beginning of time, we come to understand the shape of the potential human domain. It ranges from the soils of home to the sands of Mars, and includes thousands of small, weird places as well.

Extending human experience to these limits *is* the sustaining purpose of human space flight. This purpose is neither easy nor quick to achieve, yet it beckons. President Obama has said:

> "Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite" [2].

These 34 words define a powerful vision that captures four key yardsticks to measure our ambition and progress: making space our home; far from Earth; using what we find there; irreversibly. This open-ended challenge is not fixated on a particular destination, nor is it intended to be the province only of government action; rather it is about humanity stepping outward, to all attainable destinations, forever.

Recognizing that stepping out into the solar system is the underlying goal of our HSF investment can help clarify priorities. Moon and Mars are both meaningful and worthy because they are both eventually attainable. GEO satellite servicing is meaningful and worthy because it offers us the earliest possible human toehold outside the geomagnetic shield. Proposing to step—rather than leap—tempers vision with pragmatism, because it matches the reality of our limited resources.

The most serious sociological challenge to an open-ended vision—one felt by both space advocates and the industrial-political machine—is that there is no urgency discernible in it. Most often this dissatisfaction is formulated as the criticism that NASA has no 'clear destination.' But naming one would not by itself spark urgency, and the 'long view' requires a kind of patience not evident in American culture. The dilemma for space supporters is that those who seek faster progress cannot command the broad popular mandate needed to make it so. In today's world they can neither arrange a significant increase of public investment for an aggressive HSF vision nor sustain it for several decades. And the evidence suggests that neither strident Senate speeches nor op-ed essays can redress this structural mismatch.

For most Americans, non-urgent advancement of HSF capability is a non-issue, but for space supporters it is unpalatable. Noble though it may be, HSF is a 'boutique' technology. Electricity, refrigeration, motive power, computers, and networking are technologies that have played a very different role in humanity's progress. They were developed and became ubiquitous because they directly improved the human condition so dramatically that their value was never seriously questioned. However, HSF is seriously challenged to compete with today's other technology frontiers: biotechnology, nanotechnology, clean water, robotics, artificial intelligence, genetic engineering, manufactured food, alternative energy, and climate change. Indeed HSF is self-limiting when cast as equivalent to 'space exploration;' the farther out it looks, the less relevant it is to urgent considerations. This is a second structural mismatch that cannot be wished away.

Thus a core problem for 'why HSF' is: How might stepping out into the solar system be made *central enough to society's needs* throughout the 21st century to stimulate and sustain increased public investment in it?

Antarctica and the continental shelves offer instructive models. Both are destinations analogous to space: remote, alien, risky, and needful of advanced technology. Humanity has stepped out onto Antarctica for routine scientific

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