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HISTORY HINTS AT A DECENTRALIZATION OF FUTURE SPACE ACTIVITIES

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To highlight opportunistic scenarios for future space activities, patterns from history are compared to the history of spaceflight. It appears that NASA's "Vision for Space Exploration" (2004-2010), is similar to the "pride before the fall" of incumbent leaders when faced with new challenges. In this pattern, the incumbent will falter and other service providers will rise in prominence, which in turn, changes the character of the activity. In the case of civilian space activities, major change agents include robotic instead of human activities, entrepreneurial joy rides, commercial launch services, and space programs in other countries. Another influential factor is that Federal funding for the US space program has remained steady, but insufficient to complete the "Von Braun visions" which defined the "space age." Future scenarios, based on historic patterns, hint that space activities will become decentralized and diverse, with several different types of organizations filling different facets of the overall possibilities. Within these scenarios, opportunities are identified.

I. INTRODUCTION

This paper is a combination of scholarly reflections and subjective judgements intended to predict future opportunities in civilian space activities. It is not an advocacy paper, nor is it suggesting that certain actions be taken. Instead, it is extrapolating future scenarios based on comparing the history of civilian spaceflight to recurring lessons from history. Although predictions, by their very nature, are subjective and questionable, it is hoped that these predictions will make it easier to diagnose the current trends in civilian space activities and help others to find opportunities amidst those changes.

Much of the content of this analysis evolved from a 2006 thesis written for a masters degree in "physics entrepreneurship" [1]. Although that thesis focuses on a business case for a non-profit organization, it also assesses the implications for future space activities in general. A version of these implications appeared as a 2007 opinion piece in *Spaceref.com*, "Plan B for Outer Space" [2]. In particular, that essay predicted the end of the "*Vision for Space Exploration* [3]" would occur around the spring of 2011 (albeit with a wide uncertainty offered of ± 3 yrs).

The scholarly references used in this analysis deal with the cycles of technologies and businesses as they transition from one era to another. For a comparative context, consider how the jet age eventually supplanted piston-propeller aircraft, how aircraft carriers became more important than battleships, how photocopiers supplanted carbon paper, etc. Comparisons to the evolution of the space program are presented, where the revolutionary transformations are more a matter of markets and players than of revolutionary technology.

The *subjective* observations that influence this study are based on the author's 30-plus years at NASA (1978-2010) and impressions from growing up watching Apollo on television and recreational studies in the evolution of aircraft, racing cars, and submarines. Within NASA, the author is most known for his work on Breakthrough Propulsion Physics [4].

II. GENERAL REFERENCES & INFLUENCES

Although citations to certain assertions are offered where they occur, many of the influential references and experiences apply throughout this entire paper. Short descriptions of these follow, and include: lessons from an entrepreneurial masters program, life experiences of the author, and the abundant commentaries about the civilian space program.

Entrepreneurial Education

A masters degree in "Physics Entrepreneurship" from the Case Western Research University, in Cleveland Ohio [5], included the study of a central textbook [6] and numerous other books and journal articles that discuss typical patterns of how organizations can capitalize on technological or market developments.

The following were most influential: Clarke's *Profiles of the Future* [7], Kuhn's notion of "Paradigm Changes" [8], Dyson's perspective on tool-based revolutions [9], and Foster's book on innovation [10].

Arthur C. Clarke's *Profiles of the Future* discusses patterns of technological development and attempts to predict the technologies that will emerge and when they will emerge (with uncanny accuracy). Over the course of its revisions (1962-1973), Clarke posited three "laws" regarding the reaction to *revolutionary* advancements. While these oft-cited laws are not *laws* in the strictest sense, they do echo recurring themes from numerous references. Quoting [7]:

1. When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong.
2. The only way of discovering the limits of the possible is to venture a little way past them into the impossible.
3. Any sufficiently advanced technology is indistinguishable from magic.

[End quoted section].

Regarding the first law, which is in reference to such infamous quotes as: "Space travel is utter bilge." [Dr. Richard van der Riet Wooley, one year before 1957's Sputnik], it is equally important to remember that history includes many errant ideas that were indeed critically flawed. Distinguishing these is easy in retrospect. The viable ideas survive (along with the infamous dismissive quotes) while the errant ideas tend to be forgotten. To make it easier to distinguish these as they unfold, it is useful to learn how to recognize the historic *patterns*. (An example of how these patterns are applied to the search for breakthrough spaceflight is in the last chapter of *Frontiers of Propulsion Science* [11].)

Kuhn's book, *The Structure of Scientific Revolutions,* talks about the notion of *paradigm shifts;* when old perspectives are replaced by newer perspectives. Although cast in terms of science, the patterns are nonetheless consistent with the broader pattern of how new ideas supplant obsolete ideas [8].

In Freeman Dyson's Imagined Worlds (1997) scientific revolutions are cast as the byproducts of new tools. As examples, Dyson cites how the telescope led to Galileo's insights and how X-ray diffraction led Crick & Watson to understand DNA structure. The pertinent theme is that when new tools become available, new opportunities emerge that precipitate further change [9]. By noticing and extrapolating the consequence of new tools (even outside the discipline in question), one can prepare for future changes.

In Foster's. *Innovation: The Attacker's Advantage*, the pattern of how revolutionary technologies supplant incumbent technologies is highlighted with numerous case studies. This reference goes into detail about the typical pattern of how incumbents interpret and react to new ideas. That reference also makes clear distinctions between *revolutionary* and *evolutionary* innovations. The key assertion is that simply improving existing technology is not sufficient to sustain competitive advantage and the incumbents tend to be the least able to adapt to revolutionary advancements [10]. Since the difficulty to adapt has been the downfall for many incumbents, noticing the symptoms is crucial for maintaining the vitality of any organization.

One more reference that applies is about the psychology of self-perception. Although this pertains on an individual level, these trends can compound when integrated over whole organizations and enhanced by "groupthink." [12]

Studies have shown that those who are most incompetent also lack the competence to realize their incompetence [13]. This is not a glib comment. This is a real psychological characteristic that compounds the difficulty of addressing both the supportive and pedantic reactions to emerging changes.

The cited study, by Kruger & Dunning, tested many different perceived skills, including humor, grammar, and logic; and the trends were similar throughout. The poorest performers are the least aware of their limitations. There is, however, a crossover point typically with the third quartile who tend to accurately judge their ranking. The most competent quartile has the opposite perspective. They tend to underestimate how well they fare compared to their peers. Although they accurately estimate their test scores, they tend to over-estimate the performance of others. Or in short, there is a natural tendency in people to consider themselves to be in the "above average" 3rd quartile, regardless of their actual ranking.

Such self-awareness errors get in the way of accurately recognizing emerging trends. As much as this can inhibit incumbents from recognizing how soon their current practices will become obsolete, it can also impede pioneers from effectively implementing change.

The study also found that raising the skill level of the less competent helps them better realize their limits. By teaching the less competent how to improve their skills, they become more aware of their limits.

In the context of this paper, it is hoped that by explaining the patterns of change, both the incumbents and pioneers who are reading this will pause to consider the limits and consequences of their *implicit* perceptions. When considering that half the people reading this – by definition and by the evidence – are below average and don't know that they are below average, it is prudent to pause to re-consider our perspectives. The same is true for this author.

Lessons from Author's Life

The author started as a coop student at NASA's Kennedy Space Center in 1978, followed by a full-time career at what is now the NASA Glenn Research Center, spanning 1982 to 2010. During that tenure the author founded and led the "Breakthrough Propulsion Physics Project" (1996-2002) which examined such visionary ideas as gravity-control space drives and faster-than-light travel [4]. This topic is a classic example of revolutionary pursuits amidst an established organization. Those experiences influenced the assessments in this paper.

In addition, as recreation, the author studied the evolution of aircraft, racing cars, and submarines –

fields where the very same patterns occur. What is surprising from these examples is how obvious the trends are in retrospect and how indifferent the incumbents appear when the changes are emerging. Most often it takes some dramatic incident before the incumbents realize that the change is unavoidable.

One example of such a transformative incident is how British racing cars transformed the American *Indy 500*. It started in 1960, when an invited visit brought a mid-engined British *Cooper-Climax* to the race. Despite having only a 2.5 liter engine compared to the American 4.2 liter *Offenhauser*s, it achieved competitive lap times [14]. Three years later, while the Americans were still limiting themselves to improvements to the same basic paradigm (heavy front-engine "specials"), another British visit finally had an impact. This time it was the mid-engined *Lotus 29* sporting a Ford engine. In its debut race, it came in 2nd place. By the time that Lotus came back in 1965 to finally win the Indy 500, the changes were finally underway in America, though still not sufficient to beat the challenger [15].

The important lessons from that one example is that the incumbents – the *American Indy racing community* – were reluctant to adapt to the inevitable changes until the superior performance was *obviously* threatening. They had a preview of the looming changes in 1960, but did not take them seriously until all but one of them were beaten on the track in 1963. The other important lesson is that the revolution came from *outside* that community. The community was so preoccupied with their own way of doing things that they did not have the ability to envision methods beyond their norms.

These trends repeat themselves across so many examples that they can be taken to predict future revolutions.

Abundant News Commentary

The last sweeping influence to this paper is the news media. News articles about the changes surrounding civil space activities are so abundant as to defy listing. Despite this abundance, there are two pertinent recurring themes: 1) NASA always seems to be at a "crossroads" (or other words to that effect) and 2) Support for the space agency has been predictably flat, around $17 Billion, ±5% (2007 dollars) [16].

Checking the accuracy of that prediction (now 3 years later), let's compare it to the 2010 NASA budget of $18.7 billion [17]. Converting the 2007 flat prediction estimate to 2010 dollars yields a predicted value of around $17.9 Billion – within 4% of the actual value.

Regardless of all the past decades of advocacy, bi-partisan support, and yearning for another Sputnik moment, the evidence is overwhelming that this budget (with modest variations) is all that NASA and its supporting aerospace industry has to work with.

Facing the disparity between that level of support and the space program's more ambitious founding history, is it no wonder that NASA has been at a "crossroads" for decades.

III. REFRESHER ON SPACE HISTORY

In preparation for the comparisons that follow, here is a short refresher on the history of the United States civilian space program, focusing on those factors that are pertinent to recognizing the patterns of change.

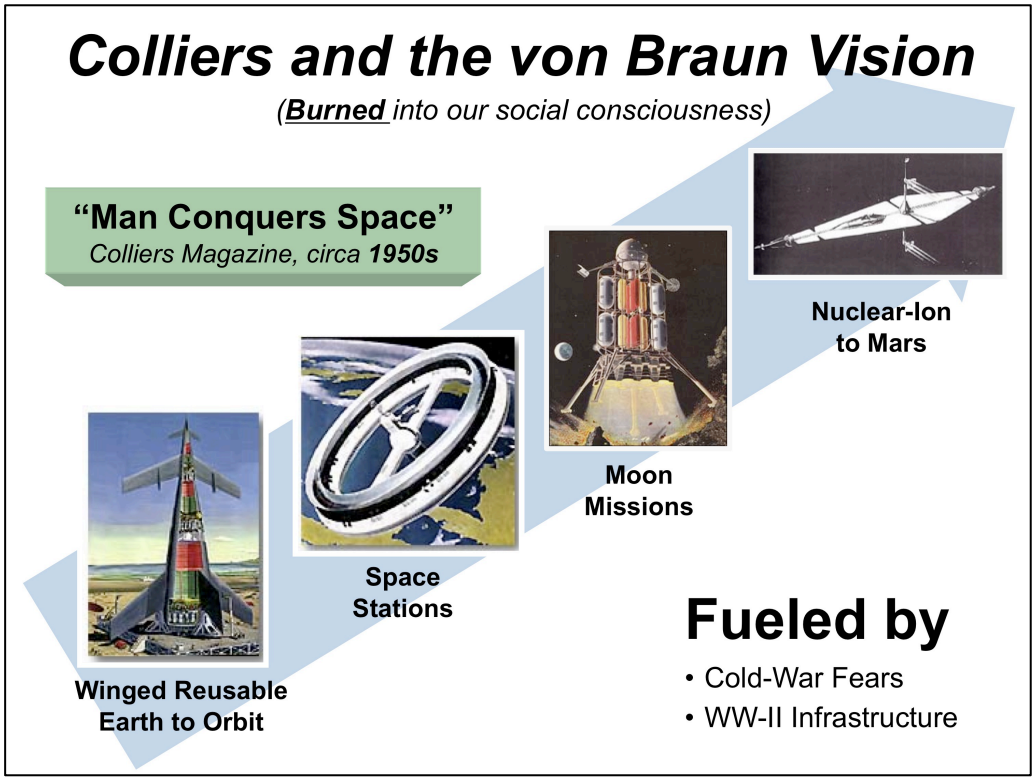
Over a half-century ago (1952), Colliers magazine cast an image of what space exploration could look like that was so alluring and compelling that, over the decades, solidified into the *only* vision for spaceflight [18]. It became *the* plan – a grand plan with winged space shuttles, orbiting space stations, human Moon missions, and eventually nuclear-ion-propelled vehicles to Mars.

This was the vision that was already in place when the 1957 security threat of Sputnik spurred the nation into action. With that iconic vision already in the minds of decision-makers, the pioneers could quickly step into action. NASA was established as *the* civilian aerospace agency a year after Sputnik, and 3 years year after that, President Kennedy made his famous speech where he articulated the ambitions for NASA; Moon missions, and "… all these other things…" [19]

Rather than following the original Colliers' sequence, the Moon landing was picked out of that plan as an early trophy goal. Once completed and once the Cold War motivations faded, the space program went back to implementing the grand plans in the original sequence outlined in Colliers, but found drastically curtailed budgets.

Fast-forward to the twenty-first century: Winged space shuttles and orbiting space stations actually exist. Although inspired by the von Braun vision, both are constrained to fit budgets and policies that are insufficient to enable the grand scale of the von Braun visions. This is the pattern that our Nation's space program has been locked into, continuing to this day.

Meanwhile, other technologies matured that were not envisioned in the original Colliers vision. For example, rather than having large teams of men observing weather patterns from a giant orbiting space station – as in Colliers – the technologies of computing, communication, and image processing, made relatively small and affordable weather satellites possible. Also missing from the Colliers' vision was the impressive ability of robotic probes instead of human spaceflight. And the last external trend was the end of the Cold War and the shift to new attentions. The romantic "space age" gave way to the "information age," with its numerous distractions.



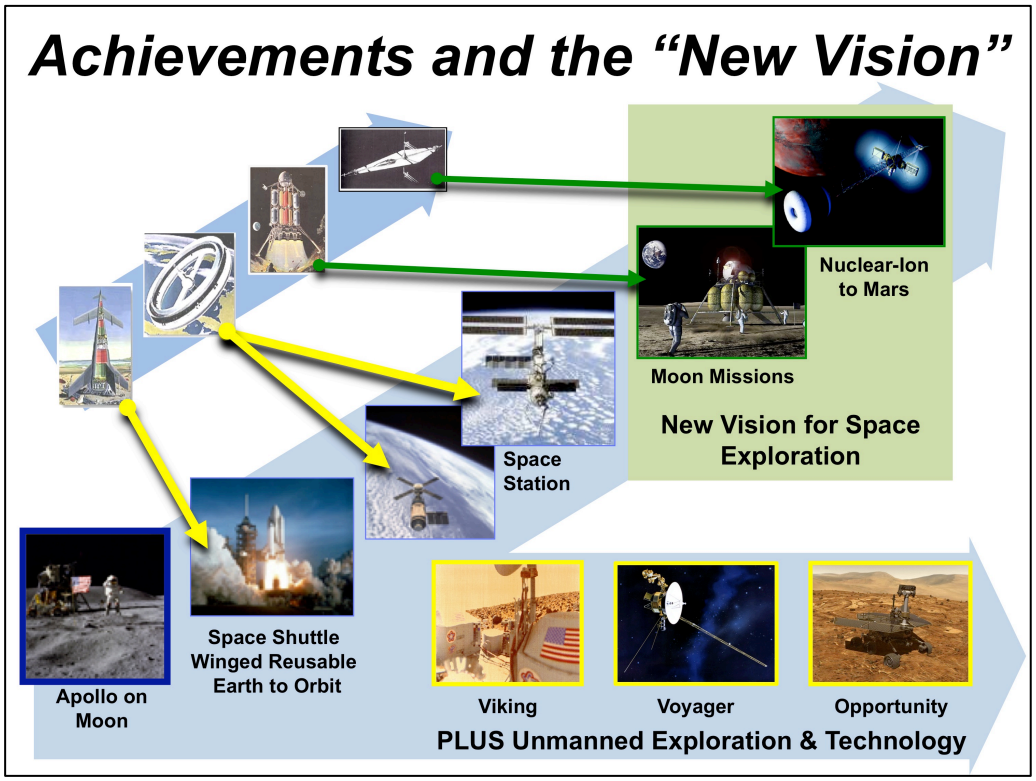


Fig. 1: Comparing the Original Colliers/Von Braun Vision to the "New" *Vision for Space Exploration*
(Colliers' artwork copyright *Bonestell Space Art*; other images from NASA)

Eventually, reassessments of NASA's future began. The Challenger accident (1986) marked the overt beginning of public and congressional second-guessing of NASA's ability and directions. An early noteworthy example is the 1990 Augustine Commission: *Advisory Committee on the Future of the U.S. Space Program* [20]. In addition to reiterating the value of the old plans, it suggested increased emphasis on unmanned exploration and science. In 2002 (shortly before the 2003 Columbia accident), the findings of the *Walker Aerospace Commission* revealed a grim message about the decline in NASA's technical prowess. The report found that the nation's aerospace industry was not healthy and lean R&D investments failed to keep a stream of continuing innovations flowing into the market [21].

Then, in January, 2004, President Bush directed a "new" focus for NASA – to return to the Moon in preparation for human missions to Mars [3]. The comparisons between the von Braun visions and NASA's "new" plan are captured in **Figure-1**. This vision wasn't really new, but rather an attempt to recapture the glory of the Apollo era. The NASA administrator appointed to implement this plan, Mike Griffin, referred to it as "Apollo on Steroids" [22].

Additionally, and quoting that same source: "Griffin was adamant the spacecraft's development won't drain resources from other NASA projects. The administrator also emphasized this mission will operate under current budgetary measures, and he has not asked for more money for the project" [22].

The budgets projected in the Presidents original plan however, were low-balled. The Office of Management and Budget estimated the funding request to only be about a third of what would be needed; specifically about $6.7B/yr needed compared to the requested $2.4B/yr (average) [23].

This disparity was no secret. When testifying before Congress about the 2007 NASA Budget in March 2006, Dr. Wesley T. Huntress, Jr. (Carnegie Institution of Washington) described the situation thusly: "NASA's plans have been called Apollo on steroids, but the budget provided is Apollo on food stamps" [24]. Those mixed metaphors, "steroids on food stamps," say much about the situation.

Reminiscent of the Black Knight in the movie *Monty Python and the Holy Grail* [25], many in NASA and its supporting aerospace industry rallied to the cause, ignoring the inadequacy of the budgets, like the Black Knight refusing to acknowledge his severed limbs. The call to duty to resume the grand vision was too captivating to pause for reality checks.

As a consequence, other aspects of NASA's responsibilities were cut to help fund the *Vision*. With the focus on *human* spaceflight, support was reciprocally withdrawn from the research to sustain technological preeminence. Recall that NASA's original 1959 charter included the responsibility for: "The preservation of the United States preeminent position in aeronautics and space through research and technology development..." [26: Sec.102(d)(9)]. Regardless of intentions, NASA has not had the resources to sustain technological preeminence and pursue the von Braun visions of human space expansion simultaneously.

The cuts to advanced missions and research actually started years before the *Vision*. Shortly after George W. Bush became president, he nominated Sean O'Keefe as NASA's administrator (2001) to eliminate the multi-billion dollar budget shortfall caused by overruns on the International Space Station [27].

Numerous examples of such cuts could be cited, but the ones listed here are those closest to the author's own experiences. Around 2002, plans were dropped for an interstellar precursor probe to the Heliopause [28]. In 2003, owing to pressures of congressional earmarks, advanced space propulsion research was completely zeroed out. Quoting from the 2002 Federal budget [29: p.325]: "Finally, the Congress earmarked funds for a low priority propulsion lab by cutting the very research the lab it is meant to support" (sic). When Mike Griffin was asked about resuming support for advanced propulsion research during a January 2006, speech at the NASA Marshall Space Flight Center, Griffin responded with an emphatic "No" [30]. In February 2006, despite earlier promises to the contrary [22], funds were transferred out of the science budget into the Shuttle budget [31]. Around May 2007, all of the following were cut: Lunar Robotic Precursor Program (scouting ahead for the astronauts' Moon base) [32], the "Terrestrial Planet Finder" (would have placed a network of detectors in space to seek out Earth-like exoplanets) [33], and the NASA Institute for Advanced Concepts (research on the edge to sustain preeminence) [34].

Even when the NASA Institute for Advanced Concepts was funded, it was limited only to supporting ideas that were already mature enough to be tested (as opposed to exploratory research) and there was no funding to apply the findings to NASA projects [35]. Without such funding, the innovations could not make their way into NASA missions.

Although human spaceflight and technological preeminence were synonymous in the 1960s (before the technology of human spaceflight existed), by the time of the *Vision*, these became divergent options.

In an informal and unscientific survey by the author in April of 2009, the following question was posed to two different audiences: "When you think of NASA's identity, do you think of *human spaceflight* or *technological prowess*?" Co-workers within NASA predominantly answered: "human spaceflight," while citizens outside of NASA (specifically attendees of a

lecture about space and science fiction) answered almost unanimously: "technological prowess." While the crudeness of that survey limits its credibility, that there was such disparity between internal and external perspectives is worthy of deeper reflection.

The idea that innovation within NASA was taking a back-seat to ambitious human spaceflight was felt inside NASA too. In a public blog on March 5, 2009 [36], and with a sequel on March 16 [37], NASA's Wayne Hale provided personal commentary plus two YouTube videos to illustrate how NASA treats innovation and, respectively, how it *should* treat innovation. The traits in those videos follow the classic symptoms of a mature organization that is more focused on continuing its legacy than on adapting to new opportunities and constraints.

And finally, the 2009 Augustine Commission explicitly raised the lingering mismatch between what is expected of NASA and the amount of resources devoted to NASA to fulfil those expectations [38]. Or to put it metaphorically, the reality check on the *Vision* finally bounced for the last time.

At the time of this writing, it is still unclear what will become of the priorities and missions within NASA [39]. That uncertainty is probably already familiar to most of this audience. What is probably not familiar is how closely these events fit historic patterns and are likely to foreshadow future events.

IV. PATTERNS FROM HISTORY

Whether in business, technology, or especially in technology-based businesses, there is a recurring cycle regarding the introduction of new methods, their rise to dominance, and eventual obsolescence. While variations to this pattern exist, the general scenario outlined next is a version that closely resembles the aging of the "space age," so that comparisons will be easier to recognize. Other variants have deeper cycles of product variations or more competitive origins. Nonetheless, the overall pattern is the same.

To begin, consider this succinct scenario for how new ideas supplant older ideas. The S-curve evolution shown in **Fig. 2** is typical of any successful technology. The pattern of the earlier S-Curve begins with modest investments with only minor advancements until a breakthrough occurs. The breakthrough, at the lower knee of the curve, is where the technology has finally demonstrated its viability. After this point significant progress is made as continually improving embodiments are produced, one after another, and the technology becomes widely established. Eventually, however, the physical limits of the technology are reached, and continued efforts result in little additional advancement. This upper plateau is the "point of diminishing returns." To go beyond these limits, a new alternative (with its own S-curve) must be created [10, 40].

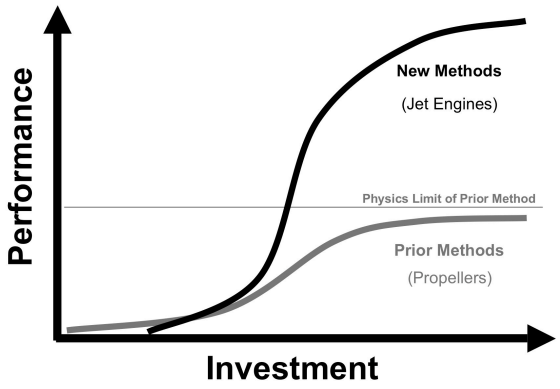


Fig. 2: S-Curve Pattern of Advancements

Shifting to a new S-curve is what is meant by pursuing "revolutionary," "disruptive," and "out-of-box," advancements.

History has shown that simply improving existing technology is not sufficient to sustain competitive advantage [10, 40]. For example, jet aircraft did not result from mastering piston-propeller aircraft. Transistors were not invented by mastering vacuum tubes. Photocopiers did not result from mastering carbon paper. The recurring theme is that entirely different operating principles were pursued to surpass the limits of prior technology and thus sustain competitive advantage. It is time to look for revolutionary approaches when the existing methods are approaching the point of diminishing returns.

It has been found that it is most difficult for incumbent organizations to consider such alternatives when their familiar approaches are at the point of diminishing returns [10, 40, 41]. By then, the institutions have become too uniquely adept at their accrued technology to consider alternatives. They are also tied so closely with their existing customers that it is difficult to even recognize new opportunities.

Because new approaches emerge in a still-developing state and have unfamiliar principles, it is also difficult for the incumbent to assess their merit properly. This difficulty is compounded since the incumbents use their prior values to judge the new approach, values that are rooted in the evaluation criteria for the different, *prior* technology. For example, it would be like assessing the value of steam ships in terms of the efficiency of rigging sails.

Even the notion of finding new markets for prior technology is resisted in incumbent organizations. The term for reconfiguring existing technology to address a new opportunity is "architectural innovation" [41]. Even here, the incumbent organizations will typically dismiss such innovations because the new opportunity is seemingly irrelevant when viewed per their prior values.

Additionally for architectural innovations, their value is even harder to appreciate because the technical aspects of the innovation do not appear to be noteworthy advancements.

Another factor exacerbating this ambivalence is the loss of "absorptive capacity" [42]. As organizations mature they shift their focus from the launch of their original, pioneering product to taking care of the day-to-day business of producing and improving that product. They tend to turn inward and reduce the timeframe of their attention span. They lose touch of the changes occurring around them [43]. Often motivated by cost-cutting measures, they cut back on in-house research and external interactions (e.g. attendance at professional conferences, trades shows, and training). The result is that the organizations lose the ability to notice and incorporate external advancements into their own product lines [40-43].

Considering these patterns, it is not surprising that the emergence of revolutionary advances often come from outside the established organizations [8, 10, 40-43]. A classic aerospace example is how the Wright Brothers (bicycle mechanics) succeeded in heavier-than-air manned flight well in advance of the government funded (Smithsonian Institution) aerospace research of Samuel P. Langley. Another example is the previously mentioned British Formula-1 cars affecting the American Indy 500 [14, 15].

Such departures from legacy approaches have also been referred to as "paradigm shifts." [8]. The organizational challenge when dealing with paradigms is the implicit value system used to judge emerging possibilities. With paradigms there are implicit commitments within incumbent organizations for setting work priorities. This results in a reflexive tendency to dismiss novel approaches that are inconsistent with the established paradigm.

The expression, "pride before the fall," has been used to describe the point when the incumbents have finally noticed that things are changing, but fail to adapt [10]. Instead, the organizations attempt to recapture their prior glory by re-running their legacy product in a grander manner in an all-out last-ditch effort that robs the organization of internal resources. They pine for a return to their founding allure, the era when they first demonstrated their superiority. Their "new" product line is merely an improved and re-packaged version of their historic products. Meanwhile, their competitors are launching genuinely new products that are based on contemporary opportunities. Failure of the incumbent becomes evident only when their "new" product fails to garner the expected enthusiasm. That failure is exacerbated when younger organizations are stepping up to fill contemporary needs [10, 40-43].

In Foster's book, the example of a sailing ship company is described. Instead of adapting to the opportunities offered by steam propulsion, they produced an impressive new sailing ship with more masts and sail area. As Foster put it, however, both that ship and its company *went under* [10].

After this point, a broad transition occurs. Numerous new service providers enter the market with their own new paradigms [44, 45]. While these vie for market dominance, the incumbent will then implement either Plan A, or B, below, but even with these there is no guarantee of success [40, 41, 43]:

Plan A: The incumbent reinvents themselves by first abandoning their old priorities in favor of new priorities that are consistent with the changes that occurred around them. Whether this shifts to using new technology or branching into new markets depends on the specifics of those changes. Armed with their established infrastructure (i.e. distribution chains), it will be easier for the incumbent to introduce new products into market (at least for a while before the new-starts get established). The catch is that these new products must actually be *new* – tailored to fit contemporary needs and resources and in a manner better than the emerging competition [41].

Plan B: The incumbent attempts to sustain their current customer base and product line, but by reducing their activities to fit within their now reduced market share. Their product line is modified to address a sustainable niche market.

Even with the emergence of superior alternatives, some product lines can still survive. Examples include sailing ships, propeller aircraft, custom vacuum tubes, and even carbon paper (i.e, as imbedded in the backs of checks in check books). Although supplanted by superior technology (respectively steamships, jets, transistors, and photocopiers), the older technology survives in smaller niche markets [10].

Regardless of how the details play out, the emergence of new products or markets marks the transition into a new era. During this transition the new service providers will vie for dominance, with some failing, others being reduced to niche markets, and with some rising to dominance. Then, as before, the new dominant organizations will someday mature and will eventually face new changes. In keeping with historic patterns, they too will likely have difficulty noticing and then adapting to the next wave of changes [44, 45].

V. PATTERN COMPARED TO SPACE PROGRAM

In the context of the historic patterns, the *incumbent* is NASA's manned flight program as cast in the ideals of the von Braun and Colliers goals. The contemporary challengers predominantly include: the legacy of Apollo's success, the end of the Cold War, the rise of unmanned capabilities (automation, computing, robotics, etc.), and the accessibility of new markets.

The *incumbent* includes the decision makers throughout the entire civilian space program: the President(s), Congress, lobbying aerospace industry, NASA itself, and even the space advocacy societies.

The major *explicit* strain facing the incumbent has been the lingering mismatch between the idealistic goals and the resources allocated to accomplish those goals. After decades of advocating for a change in resources, even with bipartisan support, and pining for another Sputnik moment, the evidence clearly shows that the resources are predictably flat to within ± 5%.

The hopes for another Sputnik moment – from the rise of the Chinese space program – have not materialized. The first launch of a Chinese astronaut occurred in 2003 [46], and seven years later, the budgets are still following the flat trend.

The other changes have also been producing strain, but have typically been dismissed by the incumbent as being irrelevant or not yet worthy of full adoption. These include the side-effects of NASA's own success, the rise of robotic capability, the dawn of space tourism, and multiplicity of providers for space access.

Side-effects of NASA's Success

Consider the impact of Apollo. Human spaceflight, which was once just fantasy, became real. The technologies that made that possible seeped into other endeavors.

It can be argued that the impeccable safety record raised expectations unrealistically high. For example, if we could go back to the 1950's, it is likely that people would expect spaceflight to be at least as dangerous as military training exercises. Although debatable, it is fair to conjecture that public and congressional tolerances for spaceflight risk would have been higher had the Apollo program encountered more fatalities before it finally succeeded at landing a man on the Moon. Such experiences would have set a different precedent – a different paradigm about the risks versus values of spaceflight.

Another consequence of NASA's success was the rise in technological prowess for miniaturized circuitry and computers – advances that not only made onboard computers possible, but that also boosted the capabilities of unmanned probes.

Images of the lone Earth – or as Carl Sagan called it, "Pale Blue Dot" [47] – helped instil a greater sense for protecting the Earth's environment. In addition, the first Moon landing helped remind divergent cultures (who watched via television) that we share a common humanity [48]. Both these images introduced a deeper sense of our shared habitation on a limited planet. This led to a paradigm shift from seeing just the threats from competing countries to seeing our shared threats to global survival.

All of these paradigm shifts were caused by the rise of manned spaceflight. They are no longer new or novel. These successes set even more changes in motion. NASA went from being a pioneering new-start to a successful incumbent.

End of Cold War

When Sputnik occurred, it triggered *survival* fears. Once Apollo demonstrated American competence in space and the Cold War ended, the space program slipped down the priority chain to become a discretionary activity rather than a perceived key to our survival.

To retrigger a Sputnik moment, it would again take a fear of our *survival*, such as an incoming doomsday asteroid.

Rise of Robotics, Electronics, and Communication

The emergence of robotic technology, from the improvements in computers, sensors, communication, effectors, and video, created a significant competitor to human spaceflight. It can be debated that this is a "revolutionary" technology in contrast to human spaceflight, that if embraced, would eventually revolutionise space exploration in general. Without the huge costs to sustain human life support, the sights and sounds of remote dangerous worlds can be brought safely into living rooms across the whole world.

Additionally, implementing advanced propulsion and power technology on robotic spacecraft would be less risky than with human spacecraft.

This asset was not available to the visionaries of the 1950's. This is, however, an invitation to the next wave of visionaries and entrepreneurs. Closely associated with that is the broad accessibility of this information over the Internet. Eventually, at least in terms of what is being watched, the broader population now has more influence over future decisions.

New Markets, New Players

And the last category of changes is the rise of new markets, such as space tourism. In keeping with historic patterns, this is a revolutionary change from outside the incumbent. Jumpstarted by the *Ansari X Prize*, there are now a variety of individuals picking up space exploration on their own. The X Prize started as a contest for $10M to the first private team to carry people to over 100 km altitude, return them safely to Earth, and repeat the ride within 2 weeks. It was won on October 4, 2004 (the 47th anniversary of Sputnik) by a vehicle designed and built by Burt Rutan's *Scaled Composites* and financed by Paul Allen [49].

The space tourism entrepreneurs are examples of *architectural innovations*. They are taking existing technology and applying it in new configurations and to reach new markets [41, 44]. This example is relevant in

the context of identifying *obsolescing values*. As evidenced by the emergence of such firms outside the incumbent aerospace organizations, it is clear that the original values that drove the emergence of spaceflight are no longer complete.

In other words, the criteria against which early spaceflight emerged are no longer the only drivers of future progress. Significant changes have occurred in societal values, technological options, and emerging science.

Summary of Changes After the "Space Age"

Here is a summary list of major changes that occurred since the dawn of the space age that are now influencing the future regardless of whether those influences are recognized:

- Unmanned explorations (satellites, rovers, Hubble, etc.) continue to produce astounding discoveries at orders of magnitude less cost and risk than human spaceflight.
- A survey reflects that younger citizens are more inspired by Mars rovers (84%) than by sending humans to the Moon (29%) [50, 51].
- Commercial, *unmanned* satellites are now routine.
- The *International Space Station* really is an *International* space station (diverse people coming together for the common good). Precedents have been set for human space expansion to become a multi-national endeavor.
- Other governments are now space-faring. The United States and Russia are no longer carrying the burden for all humanity. At least the following additional governments have developed their own launch capability [52]:
  - Countries of the European Union
  - Japan
  - India
  - China
- The perceived survival threats shifted from being about Soviet domination to now include:
  - Doomsday asteroids
  - Shifts in the habitability of Earth's environment
  - Overpopulation induced famine and disease
  - Terrorists
- There is a new pathway for human spaceflight; *tourists* instead of an elite *astronaut*/*cosmonaut* corps.
- The Russians are capitalizing on space; securing launch services in cooperation with the United States, and selling tourist visits to the International Space Station [53].
- Many wealthy people are investing in space more for its *importance* and *coolness,* than for raw *profitability*.
  - Elon Musk (*PayPal*) launched *SpaceX* entrepreneurial launch services [54].
  - Paul Allen (*Microsoft*) helped bankroll Burt Rutan's spacecraft that won the first X-Prize, and he also gives tens of millions to the Search for Extraterrestrial Intelligence (SETI) [55].
  - Sir Richard Branson is launching *Virgin Galactic* – kicking off $200k joyrides to the edge of space (planned operational by 2011) [56].
  - Robert Bigelow (*Budget Suites* hotel chain fame) plans to have his company's space station operational by 2015, and already has two test platforms orbiting Earth [57].
  - Jeff Bezos (*Amazon.com*) is working his *Blue Origin* launch services [58].
- The next X-Prize, "Google Lunar X-Prize," is aiming for private rovers on the Moon [59].
- Influential participation by the general public – even internationally – is now possible via the Internet.

The contrast between *now* and the beginning of the space age is quite evident when comparing trade magazines of each era. As reflected by the book, *Another Science Fiction: Advertising the Space Race 1957-1962* [60], advertisements at the dawn of the space age present an inspiring, *fanciful* view of the future. The images in contemporary advertisements are more factual and tied to specific existing products. Comparing those media shows the difference in *character* of an emerging era to one that has matured to stable stature.

The Incumbent Response

Following historical patterns, it is not surprising that the incumbent has difficulty recognizing and adapting to the contemporary opportunities and constraints. The upstarts are dismissed as irrelevant when judged against the established visions. Phrases heard in the halls of NASA include: "But those entrepreneurs are *only* doing sub-orbital flights." "But their technology is not as advanced as ours." "Robots can never do as well as astronauts." While arguably true, these comments are missing the point that these other efforts have value on their own terms – beyond what the incumbent has done.

The 2004 *Vision for Space Exploration* is a classic example of the *pride before the fall*. Instead of de-scoping the plans to fit budgets and to take full advantage of the new power of robotics (unforeseen in the 1950s), the decision makers attempted to recapture old glory (Apollo on Steroids) while ignoring the blatant budget trends (Apollo on food stamps). Keeping to the pattern, they gut themselves in a last-ditch effort by cutting other areas of responsibility, specifically the responsibility to sustain technological prowess.

In the pride before the fall scenario, the moment of "failure" is when the launch of their new product fails to garner the expected enthusiasm from the customers,

while other service providers are emerging on the scene [10].

Consider **Fig. 3**. The image on the left is the launch of NASA's *new* rocket, a prototype for the *Ares* launch vehicle [61]. Quoting from that source: "But in a departure from the expected flight program, the dummy second stage went into a flat tumble as it continued along its ballistic trajectory instead of maintaining a nose-forward orientation." And quoting further, regarding the first stage booster recovery, ".. the main chutes were not seen." The middle image is a test flight of the Virgin Galactic's *VSS Enterprise* [56]. This vehicle will carry citizens to the edge of space for fun, and hopefully profit. The image on the right is the inaugural flight of SpaceX's *Falcon 9* commercial launch vehicle. It succeeding in delivering a test payload to orbit [54].

Ares I-X **Enterprise** **Falcon 9**

Fig. 3: Comparing 2009-2010 Spaceflight Products

Imagine for the moment that you are too young to know the legacy of these three service providers. When you look at those images and read the comparisons between what each attempted, invested, and accomplished, what impressions would you reach about the future prospects for each?

As just one example of a deeper level of detail, consider the following press release from SpaceX about their own work; "For less than the cost of the Ares I mobile service tower, SpaceX has developed all the flight hardware for the Falcon 9 orbital rocket, Dragon spacecraft, as well as three launch sites. SpaceX has been profitable for three consecutive years (2007 through 2009) and expects to remain modestly profitable for the foreseeable future. The company has over 1000 employees in California, Texas and Florida, and has been approximately doubling in size every two years." [54].

There are now multiple payers and multiple facets of civilian space activities. Nations in addition to the United States and Russia have their own space programs, with several having their own launch capabilities [52]. Commercial firms not only provide launch opportunities for payloads, but are now opening the frontier to citizens for fun and profit. For decades commercial satellites have existed providing primarily communication services. In short, the civilian space program is entering a new era with diverse players such that the paradigm of having *one* leading space agency (NASA) is expiring.

VI. PREDICTIONS

At this point in the paper, the theme changes to speculative predictions that are undoubtedly shaded by the authors perceptions. Although based on scholarly extrapolation, these should still be treated with a healthy dose of debate.

If history does indeed repeat itself, then a transition to a decentralized era of spaceflight has begun. There will be numerous players with several different niches.

NASA and the Aerospace Industry

Absent a new survivability threat to change the share of resources going to federal space activities, it is reasonable to predict that the current budgets will remain relatively flat. This, in turn, means that the magnitude of activities of NASA and its supporting aerospace industry will remain relatively the same.

What those activities will be, however, is currently being debated [39]. What is certain is that the 2009 Augustine Commission and the Obama administration are suggesting that the ambitions of human space activities be reduced to more affordable endeavors, and that work toward technological prowess be resumed [62]. This is akin to the "Plan B" incumbent response when external changes are finally realized.

Meanwhile, those that are more immersed in the incumbent perspectives are likely to cling to the prior *Vision for Space Exploration*, or more specifically its artifact, the *Constellation* program. The incumbent assertions will continue to claim merit in terms of the *prior* values that were in effect at the birth of the space age (half century ago) rather than taking stock of contemporary constraints and opportunities.

At some point the changes will be unavoidable. At worst, NASA might be reduced to just a regulatory agency for civilian space activities. More likely, it will continue with a mix of human and robotic exploration, plus research into improving the methods of air and spaceflight, but limited to the same level of resources as per the last decades.

One venue to circumvent those limits is to embark on more international collaboration.

Space Programs of Other Nations

Considering that more and more nations have their own space programs (even if only for practical reasons such as communication, navigation, and monitoring), the ability for those governments to collaborate and share the cost of more ambitions missions becomes enhanced.

The *International Space Station* has already demonstrated that despite differences in culture,

currencies, and fiscal calendars, nations that were once enemies are now making joint progress.

In the context of human history this is not a trivial achievement to be taken lightly. This marks a precedent that bodes well for the survival of humanity. Considering those factors, it is fair to predict the nations of the world will work together toward significant human expansion into space – and – for protecting Earth from the hazards that all those nations share.

The Other Human Spaceflight

Meanwhile and regardless of how those government debates play out, the entrepreneurs will continue opening the space frontier. Over the coming years some will fare better than others. At least one is likely to rise to dominate the space tourism industry. It is also foreseeable that their capabilities will grow to where orbital facilities and even jaunts to the Moon will become commercially possible. Although their pace will be limited, there is no obvious barrier to stop that progression.

Accidents will happen, likely even fatal accidents. But since the heart of the motivation is *recreation* and *thrill* (like skiing) the situation is different. Instead of a committee making the decisions based on perceptions of public attitudes, individuals will be deciding for themselves to take such risks. Taunting the risks for the thrill might ultimately change the attitude of space risk. The aberrantly successful Apollo experiences that set a bias about space safety will hopefully fade away to where the risk-versus-benefits are seen on a more level footing with other risky human endeavours.

The implications of this seemingly small effort are more profound than their technology or early destinations. This effort is changing the character of spaceflight. This brings the realities of spaceflight closer to the people than NASA could.

Because NASA is legally prohibited from advertising or producing any publications that might be interpreted as lobbying for more support, NASA is effectively barred from capitalizing on the allure of space [51, 63]. These private ventures have no such limitations. They have the freedom and the tools to make spaceflight alluring and engaging. The long-range consequences of that possibility are profound.

Robotic Spaceflight

In much the same way that the *Ansari X-Prize* jumpstarted the space tourism industry [49], so too will the *Google Lunar X-Prize* jumpstart a private robotic space industry [59]. Regardless of how governmental robotic space exploration transpires, it is likely that private robotic exploration will emerge as a niche industry.

When combining this robotic ability with the growth of space tourism and its corresponding requisite growth in ability – in the USA and elsewhere – it is entirely possible that individual organizations will be able to afford their own space probes to check out destinations of their niche interests.

Imagine a future where universities compete for student enrolment by offering more enticing probe missions. The prospects of mining asteroids for profit becomes incrementally more feasible. At some point the threshold will be reached where asteroid mining becomes economically viable.

Leadership?

While NASA will still have an active role in civilian spaceflight, its efforts might not remain the leading, definitive activities. Leadership is not just a matter of resources and legacy, but rather is a consequence of who implements the most profound, positive changes. In that regard, the entrepreneurial tourism and robotic space industries might accomplish more overall change to the character of spaceflight than by adherence to the Colliers visions. Reciprocally, the implications of *international* collaboration to pursue those old grand visions might also make the most change, but not so much in terms of missions or landings, but rather in terms of the international bonding to expand human presence and to protect Earth as *humanity*, rather than *nations*.

Timing

Including dates into such predictions is even more dubious than the predictions themselves. Nonetheless and considering a number of events that might become target dates for certain goals, here is a subjective timeline.

By 2015, tourist rides will have become sufficiently common that more than just the wealthy few can participate. The first hotel will be nearing completion, spurring wishful thinking about those first zero-gravity escapades. The Lunar X-Prize will have been won and a host of companies will be vying for capturing that new market. At the 2014 "UNispace IV" meeting (United Nations conference on the exploration and peaceful uses of outer space), the issue of private real estate claims on the Moon will be unavoidable, even though no tended settlements exist.

By 2020, the 50th anniversary of the first Moon landing will pass with profound reflection, especially considering all the videos of those historic landing sites provided by privately operated rovers. Orbiting hotels will become less exciting as microgravity adaptation sickness spoiled many weekend romantic getaways. Nonetheless, the facilities are fully used by various nations to prepare for deeper human missions back to the Moon and Mars – via international collaboration. Owing to the multi-national efforts, the political resistance to using nuclear technology for spaceflight

will have passed, and projects will be underway to apply that technology toward sending humans to Mars. And finally, in step with predictions of the rise of artificial intelligence, space probes and other terrestrial devices will have matured to monkey-level intelligence.

By 2025, the strain on the Earth's environment will be driving more intense efforts to set up survival colonies on the Moon and Mars. The continued improvement in artificial intelligence will have enabled outposts on Mars to be assembled and tested with robots before the humans arrive.

Beyond this date, speculations become even more dubious. As one more wild card to consider, imagine the implications of the physics breakthroughs that could enable propellant-less space drives and synthetic gravity for orbiting outposts. The seeds for that research have already been planted [64]. Pushing for this wild card is the ambition of this author.

VII. OPPORTUNITIES

Amidst all this, here now are speculations on where opportunities reside.

With the tourism industry already well populated with promising players, the next private space adventures are likely to be with robotic probes beyond Earth's orbit. Spurred by the Lunar X-Prize, opportunities for educational probes and asteroid prospecting seem reasonable to expect.

How much would you be willing to pay to treat your grandchild to 5 minutes of piloting time for a rover on the Moon? Also the idea of a commercial venture for selling the sights and sounds from other worlds is not beyond reason. How much would you be willing to pay to tune into live broadcasts as the first probes dive into the liquids of the Jovian moon Europa or even the methane lakes of Titan?

While the entrepreneurs take the next logical *affordable* steps into space, who will take on the responsibility of the R&D to push the technology for more effective spaceflight – advances beyond the immediately affordable? Although this has been the jurisdiction of governmental support, channelled to various educational institutes and government labs, that support has ebbed to the point that other options might have to be explored. With atrophied research capabilities and the loss of absorptive capacity, can government labs alone provide this service?

The niche pursued by this author is to seek philanthropic support for research toward interstellar flight breakthroughs – research that is so long term as not to be commercially sustainable [1, 65].

Overall, there is still a gaping absence for a new, more compelling vision to replace the Colliers vision, one that actually fits contemporary circumstances. By casting these into some compelling story along with stimulating visuals that can be easily comprehended, one might very well influence the course of the next era of spaceflight.

Imagine what the artists and pioneers behind the Colliers vision might have done with our current situation; knowing the ease and effectiveness of robotic exploration, the potential for citizen joyrides into space, the shift from Cold War to global economics, the societal impact of seeing our Pale Blue Dot from space, the interconnectedness across the world via the Internet, the revelation that an asteroid killed the dinosaurs and might also kill us, and the implications of global warming.

For example, picture a future where you can tune into live video and sound from rovers on Mars; the Saturn moon Titan; or a probe swimming in the oceans of the Jovian moon Europa. Imagine taking your turn at driving a lunar rover, remotely. Imagine booking a one-nighter in an orbiting hotel. Imagine the security from knowing that your home planet is under constant watch to protect its environment and to deflect incoming asteroids. There is plenty of good stuff from which to cast new, inspiring, and productive visions.

VIII. CONCLUDING REMARKS

If history is any indicator, the 2004 *Vision for Space Exploration* marked the *pride before the fall* of the Colliers and von Braun ideals of human spaceflight. The actual "fall" was when the launch of the *Ares I-X* failed to garner enough enthusiasm to raise budgets to pay for the rest of that *Vision*.

Meanwhile, new players emerged onto the scene. Commercially, just two examples include *Virgin Galactic* and *SpaceX*. In terms of other governments, numerous nations now have their own space programs – several with their own launchers – to meet practical needs of communication, navigation, and monitoring.

Extrapolating historic trends, civil space activities are transitioning to a new era. With a multiplicity of players and activities, there will be no central dominant player or activity, but rather a host of activities each with players vying for dominance. During this transition some players will fail, some will be reduced to niche markets, and some will rise to dominance, but limited to their niche. Then, as before, the new dominant organizations will someday mature and will eventually face new changes. In keeping with historic patterns, they too will likely have difficulty noticing and then adapting to the next wave of changes.

Perhaps the Colliers and von Braun visions were so bright as to blind the decision-makers from seeing any alternatives, even though those changes have been around for decades. The old paradigm of the Space Program as dominated by NASA is dying. While NASA and its community have pined for a return of serious support to finish the Colliers vision, other opportunities have risen in the wings. Spaceflight is no longer limited

to just astronauts. The accessibility of affordable robotics will eventually intersect with marketable motivations for their use, such as educational probes and commercial asteroid prospecting.

Regarding the fate of NASA and its supporting aerospace industry, their resources show no signs of increasing or decreasing. They will, however, have to reconcile themselves to the fact that the ambitions have far exceeded the budgets for decades.

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