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CHALLENGES TO THE SUSTAINABILITY OF SPACE EXPLORATION

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NASA has an elaborate process for identifying and mitigating technical risks in its human space exploration program. However, non-technical risks—political, economic, and societal—are not captured in this process. Such risks are large in number, diverse in character, often unpredictable, and can be impossible to prevent because they are beyond the space agency's control. NASA's mission directorates are responsible for long-term strategic planning, so despite the difficulties, the Exploration Systems Mission Directorate (ESMD) must direct its attention to long-term sustainability risks and the development of mitigation plans. This article surveys long-term risk factors and, where possible, makes suggestions on mitigation approaches for consideration by ESMD and NASA's top management.

> By its very size, big science cannot survive in isolation from the non-scientific spheres of society. It has become an economic, political, and sociological entity in its own right.[1]

By the time the quote above was published in 1992, there already was wide recognition that the nation's "social contract with science," as some have called it, was evolving in ways that increased its interdependence with broader society, increasing demands for relevance to societal needs and for transparency in decision-making and agenda-setting. Generally, since World War II, American society has seen the pursuit of scientific and technical knowledge as intrinsically good and useful—as long as the nation maintains its input into the reservoir of knowledge, the system is working and the application of that knowledge will take care of itself. The political and economic environment that has developed since the early 1980s, however, undermines the sustainability of this paradigm. Large science and technology budgets are increasingly difficult to justify, if the enterprise is isolated from societal

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needs.[2] Political leaders and their constituents expect measurable results that contribute to problem resolution. Sustainable investment in science and technology on this scale requires accountability to societal goals to maintain political support.

NASA's human space exploration programs, as currently envisioned and implemented by the agency's Exploration Systems Mission Directorate (ESMD), clearly will undergo the continuous scrutiny that is characteristic of today's political environment. Exploration projects span decades, covering numerous presidential and congressional terms and multiple generations of scientists and engineers. Moon-Mars exploration is often discussed as a 30-year effort, but in reality, it should be viewed as an open-ended project. NASA's history demonstrates that the agency's greatest successes, even in the wake of serious setbacks, have been on programs with limited, well-defined objectives and finite durations (e.g., Apollo, Skylab, numerous space science missions). On the other hand, open-ended programs with less clearly defined (or too many) objectives have proven problematic, undermining their political and economic sustainability (e.g., shuttle, space station, next-generation space transportation systems). Human exploration of the solar system, starting with the Moon, is the ultimate open-ended program. To ensure its sustainability, NASA must approach it in a different manner than anything in its previous experience by planning from the beginning for ongoing operations in cooperation with a variety of domestic and international partners.

Obviously, many challenges will need to be overcome during the course of the effort, such as budget and schedule shortfalls, technical setbacks, and fluctuations in political salience and public support. While cost, schedule, performance, and safety tend to be at the top of the agenda for those closest to the project, these represent only a portion of the sustainability concerns. Long-term sustainability risks challenge major program goals and tend to be external to the program, beyond the control of the program's management, and often unpredictable in their timing. These types of risks—political, economic, and societal—present daunting challenges. The intent of this paper is to highlight the hurdles, bottlenecks, and potential pitfalls in the quest for long-term sustainability, and to suggest some mitigating strategies for some of them.

Inevitable Comparisons to Apollo

As NASA's exploration efforts attempt to gain momentum, decision-makers and the public undoubtedly will make comparisons to Project Apollo—humankind's only direct historical analogy. Indeed, this already has been happening within the space community and in the media, often with NASA's encouragement. The space agency hopes to demonstrate that the new project will be even more beneficial than Apollo, as well as being sustainable and affordable.[3] But, do comparisons to Apollo necessarily result in a positive outlook for the current program, as NASA hopes?

Apollo and the current exploration program share two major characteristics: human spaceflight destinations beyond low Earth orbit, and the requirement for a substantial percentage of the agency's resources over an extended period. Beyond these basic characteristics, the current effort is a different program in a very different political environment.

Space exploration does not hold the same strategic importance and priority on the national agenda as it did four decades ago. In 1961, NASA Administrator James Webb and Secretary of Defense Robert McNamara suggested that Apollo was "part of the battle along the fluid front of the Cold War,"[4] a view that was largely shared by the executive branch,[5] the Congress, and the public. No such strategic imperative exists for human spaceflight today. In his 14 January 2004 speech announcing the exploration initiative, President George W. Bush called it "a journey, not a race,"[6] and generally emphasized human destiny and the desire to explore rather than any kind of national imperative. This lack of imperative was reinforced by a lack of new resources, a sharp contrast to the NASA budget of the early 1960s, which multiplied several times to accommodate Apollo. As a result, media and public response has been less enthusiastic than it was for Apollo in 1961, and expressions of disinterest and disapproval have been common from an electorate more concerned about overseas military conflict, health care, the economy, and the environment.

As indicated in Table 1, NASA's budget increased rapidly in the first half of the 1960s to accommodate the requirements of the Apollo program. During this period, human spaceflight spending as a percentage of the agency's budget peaked in 1967 and 1968 at about 61%—a level that today's human spaceflight programs

TABLE 1 NASA Budget Trends, 1959–1972[a]

Year	NASA appropriations	Percent change from prior year	Human spaceflight spending	Percent of agency budget devoted to human spaceflight
1959	330.9	–	46.4	14
1960	523.6	+ 58	84.4	16
1961	964.0	+ 84	130.6	13.5
1962	1825.3	+ 89	563.0	31
1963	3674.1	+101	1483.4	40
1964	5100.0	+ 39	2713.0	53
1965	5250.0	+ 3	2949.0	56
1966	5175.0	− 1.5	3002.2	58
1967	4968.0	− 4	3024.0	61
1968	4588.9	− 8	2809.2	61
1969	3995.3	− 13	2177.5	54.5
1970	3696.6	− 7.5	2030.0	55
1971	3268.7	− 12	1422.5	43.5
1972	3298.0	+ 1	1285.5	39

[a] Millions of then-year dollars; percentages rounded to nearest half-percent.

Source: *NASA Historical Data Book, Vol. 2: Programs and Projects, 1958–1968*, and *Vol. 3: Programs and Projects, 1969–1978* (SP-4012, 1988).

already had reached by 2006. Total human spaceflight spending from 1959–1972 was 50.8% of the agency's budget for that period, or 51.5% if the two years preceding the initiation of Project Apollo are eliminated. Contrast this experience with NASA's projected budget through 2012, shown in Table 2. Annual increases are far

TABLE 2 Projected NASA Budget Trends, 2008–2012[a]

Year	NASA budget request	Percent change from prior year	Human spaceflight spending (Exploration Systems + Space Operations)	Percent of agency budget devoted to human spaceflight
2008	17.309	–	10.715	61.9
2009	17.614	+1.8	11.023	62.6
2010	18.026	+2.3	11.384	63.1
2011	18.460	+2.4	11.762	63.7
2012	18.905	+2.4	12.055	63.8

[a] Billions of current-year dollars.

Source: *NASA Fiscal Year 2008 Budget Request Summary, February 5, 2007*.

more modest, amounting to no more than keeping up with inflation even though the percentage of the proposed agency budget devoted to human spaceflight in 2008 exceeds the Apollo-era peak and slowly climbs through 2012. This five-year plan precedes development and flight testing of the Ares 5 cargo launcher and the lunar lander, missions to the Moon, and establishment of lunar infrastructure—all of which will drive funding requirements significantly higher even if no cost overruns are experienced.

NASA projects that the rate of annual budget increases in the next decade will be similar to what is shown in Table 2. Program growth during the decade is likely to require a sustained level of at least two-thirds of the agency's budget, far more than was the case for Apollo. NASA will be in the politically risky situation of being perceived as a single-mission agency pursuing goals that have so far demonstrated a much weaker mandate than the Moon race of the 1960s.

Another important consideration is the difference in the pressures on federal spending compared to the 1960s. Apollo expenditures reached their peak at about the same time that the Vietnam War spending was ramping up and the Great Society entitlement programs were just beginning. The same year that Apollo 11 landed on the Moon, the U.S. government began a long era of deficit spending that continues today (interrupted only once, in the last two years of the Clinton administration). The result is that the interest on the national debt currently consumes 8% of the federal budget, and this is expected to continue for the near future. NASA accounts for about 0.6 percent of the federal budget, a level that is expected to stay fairly stable. In other words, the funds expended to pay interest on the national debt each year are enough to pay for more than thirteen NASAs.

If NASA budgets grow at rates that do little more than accommodate inflation, and exploration expenditures jump as new development projects (e.g., lunar lander, Ares 5, lunar base elements) begin in the next decade, other NASA activities will be squeezed, raising objections in scientific and political circles—a reaction that has already begun to manifest itself. Moreover, Congress is likely to compel NASA to pursue a "balanced portfolio" approach. Throughout the agency's history, such an approach has produced a wide variety of societal benefits in addition to the space spectaculars for which the agency is famous. It is important to remember

that at the same time Apollo was aiming for the Moon, NASA was developing communications satellites, weather satellites, deep space probes, and entirely new scientific disciplines. Decision-makers and the public will not abandon their expectations that NASA should continue work on space science and applications even as it devotes more energy to human spaceflight.

Congressional and Public Support

Space policy is what political scientists would call a "low salience" issue. Civilian space projects have never been significant issues in U.S. election campaigns, and the political parties have not engaged in organized efforts to take sides, at least not in ways that would be visible to voters. As a result, the U.S. public—even the attentive public outside of active members of the space community—has little incentive to get involved in the political process for space issues. In other words, the public typically has depended on political and technical elites to set the government's space agenda.[7]

Members of Congress are found to be most responsive to constituents, acting as their dutiful delegates, when issues are salient, signals from the constituency are clear, and consequences are traceable to the individual member's actions.[8] These conditions typically are not true in the case of civil space policies and programs, however. In the absence of clear constituency positions, members who choose to consult public opinion polls on space issues find very limited guidance. The polls are national in scope, not limited to the member's state or district, and they hold few clues as to how space funding should be allocated. Respondents are fairly evenly divided on the relative importance of human versus robotic missions, but have generally preferred scientific return over space spectaculars like a piloted mission to Mars.[9] These vague preferences have remained essentially the same in polls since the 1960s, except for brief peaks in support at the times of the first Moon landing and the space shuttle accidents. The demographics of the respondents taking each position have remained consistent as well: space supporters tend to be white, college-educated, Republican males with incomes above the national household median; indifferent or unsupportive attitudes are most prevalent among women, minorities, people with less than a

college education, Democrats, and those with lower-than-median incomes.[10]

Three decades of surveys by Jon D. Miller have cast doubt on the reliability of the public's assessment of the value of the space program.[11] Miller has found that the interested and attentive public displays disappointing results on questions of science and space literacy, and the performance of the inattentive public on these questions is significantly worse. In short, even those who like the space program and value its scientific advances would have a difficult time explaining what they have gained from it and why they feel as they do. Miller, like many other analysts, advocates improvements at all levels of public education on science and space, lest the public continue to shun involvement in decision-making on space issues. Given these findings regarding the general level of public knowledge and interest, it is clear that most congressional representatives are acting as trustees and/or party conformists rather than delegates when it comes to space matters.

Interpreting Public Opinion Polls

Since 2004, there have been public opinion polls specific to the exploration mission that reveal new and ominous signs to policymakers and NASA. The most visible has been a series of polls commissioned from the Gallup organization by the Coalition for Space Exploration, an alliance of companies and professional organizations formed in 2004 to promote the exploration program.[12] Numerous press reports and NASA's website[13] have focused on the generally positive responses to the question: If NASA's budget did not exceed one percent of the federal budget, to what extent would you support or oppose this new plan for space exploration? Would you strongly support it, support it, oppose it, or strongly oppose it? Jeff Carr, chairman of the Coalition, summed up the responses this way: "Cumulative results indicate that, over the course of time and despite varying world and national circumstances, the American people still strongly support space exploration and are willing to support its funding at current levels or even slightly increased."[14]

A closer look at the detailed results reveals a more nuanced and less optimistic interpretation. The three Gallup surveys were performed in June 2005, March 2006, and August 2006. Press

coverage failed to note that between the first and last survey, there were significant negative changes in the results. Responses of "support" and "strongly support" dropped 11 points (from 77 to 66%) and responses of "oppose" and "strongly oppose" increased 8 points (from 20 to 28%). A possible explanation for the downturn in support is that the first survey was conducted a month prior to the space shuttle's long-anticipated post-Columbia return to flight, causing a temporary positive bump, but this was followed by nearly a year without shuttle flights due to continuing problems with insulation foam shedding.

The Gallup surveys were broken down by age, gender, education, political identification, voter registration, and region, but not by ethnic or religious group. The results in each of these categories roughly parallel those seen over the past three decades. The long-duration support required to sustain exploration ambitions, however, suggests that particular attention should be paid to younger age groups that will see exploration efforts develop throughout their careers and may have an outlook on human spaceflight different from those who lived through the Apollo era. Unfortunately, in each of the three surveys the youngest age group (18–34) constituted only 16–17% of the sample—the smallest of all the age groups. According to the Sampling Tolerances discussion in the Gallup report on the August 2006 survey, this age group's results, considered separately, have a sampling error three to four times larger than the three percent error rate for the study's entire sample.

A study by Dittmar Associates conducted in August through November 2004 sought information similar to the Gallup polls on support for NASA and its exploration goals, but dug deeper with questions on human versus robotic missions, Moon versus Mars, appropriate level of NASA funding, and relevance of NASA to daily lives. While the overall results of the study were positive for space exploration, it revealed some troubling issues in its analysis by age group.[15]

The youngest age group in the Dittmar study, 18–24, will contribute their taxes to the exploration program for the next 40 years. This age group includes those in college, graduate school, or just starting their careers, making it more focused than the Gallup grouping of 18–34. The Dittmar team was surprised by their primary finding for the 18–24 group: disinterest. The one thing

that excited the members of this cohort was the robotic exploration of Mars, which received good support across all ages except those over 75. The greatest concentration of support for human exploration came from the baby boomers, who will reach retirement age in 2010–2029, precisely the time when the exploration effort needs sustained momentum.

Dittmar Associates did a follow-up study[16] in October 2005 through February 2006 with an 18–25-only group, larger than the similar age group in the 2004 study, to further investigate this surprise finding and make sure it was not just an artifact of sampling error. The results corroborated the findings of the original study and yielded the following:

- 55% of respondents were aware of the exploration plan, but the typical extent of their knowledge was that it is "something about the Moon";
- 27% expressed doubts that NASA had gone to the Moon;
- 39% thought nothing useful has come out of NASA; and
- 72% believed NASA money would be better spent elsewhere.

Mission-specific opinions included the following:

- 52% supported more rover/robot missions. There was particular interest in mission designs featuring telepresence;
- regarding return to the Moon, 23% identified themselves as "disinterested," 49% as "neutral," and only 29% as "interested"; and
- regarding human missions to Mars, respondents were opposed by a ratio of three to one. Chief objections were that it is too difficult, too costly, and it seems pointless.

If the results of the Dittmar surveys accurately portray the attitudes of future voters and leaders, the younger generation needs to become engaged and enthused about space in the next few years if space exploration efforts are to be sustained. The problem of disinterest among youth is compounded by the more general problem of short attention spans. It has been demonstrated repeatedly since the Apollo program that newsworthy events, both good and bad, pique the interest of the public and give a temporary boost to support for space in opinion polls. Such events are often associated

with human spaceflight: Apollo 11, Apollo 13, the first space shuttle flight, as well as the loss of Challenger and Columbia. Robotic spaceflight events also have had their share of wide recognition: the Voyager encounters with the outer planets, Hubble's stunning images, and landings on Mars from the Vikings of the 1970s through the Sojourner, Spirit, and Opportunity rovers. The bump in the polls inevitably falls off, however, as the "back-to-normal" effect takes over and news coverage disappears.

Apollo 11 demonstrated how quickly public interest could drop, even for something as spectacular and historic as the first human landing on the Moon. Deflation of enthusiasm after major program events (e.g., the first Crew Exploration Vehicle flight, the human return to the Moon) can be expected for the current program as well. The situation will be exacerbated if negative news such as cost overruns, schedule slips, or catastrophic losses is perceived to dominate over positive news.

A combination of public apathy and negative perceptions may already be taking its toll. A recent Harris poll on fixing the U.S. budget deficit held a warning message for space exploration. Among the questions in the March 2007 poll, respondents were asked to pick two federal programs, from a list of 12, that should be cut to reduce government spending. The space program was chosen by 51% of respondents, topping the list by a wide margin, and more than 13 percentage points above the second choice.[17] This result indicates that approximately half of the U.S. voting-age population views the civil space program as either a waste of resources or simply a non-essential activity. If other polling results, such as the Gallup surveys discussed earlier, accurately portray two-thirds of the population as supporters of space exploration, then a significant percentage of those supporters see the space program as a luxury item that could be sacrificed in a constrained budget environment.

Changing Demographics and Interest Group Issues

Judging from surveys on the space program over the past three decades, the changing demographics[18] of U.S. voters in the coming decades may shift the balance of support for civil space programs, especially those involving human spaceflight. At least as far back as the work of Sylvia Fries in 1992,[19] it has been noted

that the segments of the voting population likely to increase their influence on the political landscape in the coming years (e.g., women and minorities) are the same ones that typically number among non-supporters in opinion polls. This does not necessarily mean that organized opposition to the space program will emerge from these groups, but it does imply an electorate less concerned about the health of the program.

The Dittmar study found women, Hispanics, and individuals living in the Midwest among the least supportive segments of the population. African Americans, people in service occupations, and individuals living in the Northeast and South were rated as soft in their support. Surveys consistently have shown women to be less supportive of the space program than men. Women are expected to remain at the current level of 51% of the U.S. population, but their interest and engagement in political activity is expected to continue growing. It is unclear whether women's lack of support will persist in the decades to come. Their opinions on space may improve as more women find more jobs, including leadership positions, in organizations involved in space-related activities. In addition, women who place high priority on problems such as health care and the environment may begin to see space technology as part of the solution—although this is largely linked to development of space applications rather than a program of exploration beyond Earth.

Hispanics—a broad designation that currently constitutes 13% of the population—also tend not to be space supporters. Hispanics are expected to account for at least 20% of the population by 2030, at which point they will be the nation's largest ethnic group. Support for space correlates with individuals that have more education, higher incomes, and occupations outside of the service sector. Therefore, it is possible that increasing living standards among Hispanics will gradually improve their support for space, but in the presence of the political and social issues this community faces (e.g., immigration law, health care, and language barriers), it cannot be guaranteed.

In addition to ethnic and gender groups, consideration should also be given to interest groups that may be directly or indirectly opposed to NASA's exploration plans. While not necessarily opposed to the concept of space exploration, some factions see U.S. civil space projects as proxies for military space activities,

including the development of nuclear-powered spacecraft and deployment of space weapons.[20] The dual-use nature of almost all space technologies fuels this suspicion and may help enlist the support of arms control groups in protests over space missions.

Fortunately for NASA, these groups so far have tended to be small, fragmented in their approach to space issues, and therefore not influential. For the past two decades, the most serious manifestation of resistance to NASA programs has been from anti-nuclear groups. There has been opposition to the launch of missions with nuclear power sources on board, notably Galileo, Cassini, and New Horizons. All of these have involved at most a few dozen pounds of plutonium to provide modest power levels to spacecraft systems for journeys to the outer planets, yet despite strict safety protocols and assessments showing minimal risk, anti-nuclear groups have responded with protests and have sought the intervention of the courts to prevent launches. This does not bode well for larger, more advanced uses of space nuclear power in the future.

At some stage in the development of the exploration architecture, nuclear power may become the solution of choice to provide higher power levels for both onboard systems and propulsion, possibly in Earth orbit, but even more likely on the Moon and in deep space. This has already caught the attention of anti-nuclear groups, which can be expected to oppose any role for these types of nuclear power sources even more vehemently than they have done for past missions. To date, the courts have denied requests for restraining orders on NASA planetary launches. It cannot be assumed, however, that NASA will continue to receive this favorable treatment. Only one successful challenge is needed to set a legal precedent that could have implications for all nuclear-powered missions that follow.

Another possible avenue for opposition to space projects in the coming years could stem from anti-globalization sentiments. The same entities that dominate space activities—government institutions and large corporations—are seen by critics as orchestrating globalization to serve the wealthy at the expense of the poor. Space technology could be seen by globalization critics as a tool of transnational corporations that exploit workers, of foreign investors who undermine local businesses, or of wealthy (i.e., spacefaring) countries that economically take advantage of

developing nations. So far, space activities have not been targeted by globalization opponents directly. There is a possibility of an anti-technology backlash akin to the Vietnam era experience, however.[21] Space efforts likely would become targets if this were to occur.

Ripple Effects from Unrelated Events

The human drive to explore and develop space cannot be divorced from the effects of national and world events. Everything is connected—politically or economically if not physically. A vast array of external influences could keep project teams from meeting their cost, schedule, and performance goals, keep the space agency from achieving its mission, and keep the space community and its advocates from realizing their dreams. Disruptive events often cannot be predicted or prevented; further, thoroughly preparing for all probable contingencies is not practical. It is still important to think through the major potential threats and identify paths to mitigating their effects, however.

The following sections highlight some categories of concern. Reactions to challenges such as those described here could result in realignment of NASA's priorities, including a diminished role for human spaceflight. NASA's research and development prowess could be redirected, as it has been in the past, to address the issues of the day. An example from the "energy crisis" days can be found in a 1970s era amendment to NASA's charter, which directs the agency to work on "ground propulsion technologies" (i.e., electric cars) and "solar heating and cooling technologies."[22] At that time, NASA also was working with the Department of Energy on wind turbines for power generation. Similar assignments that divert NASA resources and personnel can be anticipated in the decades to come.

Continued/Escalated Security Threats at Home and Abroad

Large-scale overseas engagements such as those in Iraq and Afghanistan may be with us for a while, and more may be brewing in other parts of the world. Overseas conflict is consistently one of the top issues on voters' minds at election time, so attention and resources could be diverted away from civil space issues in favor of defense and homeland security if events dictate.

Natural Disasters

Every hurricane season potentially threatens NASA's field centers in the southeast U.S., as demonstrated by Hurricane Katrina's effects on Stennis Space Center and the Michoud Assembly Facility. Johnson Space Center and Kennedy Space Center also are in hurricane zones, not to mention the scores of support contractors that reside in these locations. There also is a possibility of strong hurricanes heading up the east coast and threatening Langley Research Center, Wallops Island, Goddard Space Flight Center, and NASA Headquarters. On the west coast, Ames Research Center, Dryden Research Center, and the Jet Propulsion Laboratory are in earthquake zones.

NASA's estimate of Hurricane Katrina's damage to Stennis and Michoud was $760 million. To date, the supplemental appropriation for hurricane relief has been only half that amount—$385 million. The hurricane damage came on the heels of a two-year recovery effort following the Columbia accident. NASA estimated recovery costs for that incident at $2.3 billion when factoring in delays to the International Space Station (ISS) assembly sequence, but supplemental appropriations to date have covered only a fraction of that amount.

In the course of the multi-decade exploration program, natural disasters near NASA facilities are inevitable. As in 2005, damage could be severe, it could coincide with other costly mishaps, and appropriations for relief funding could be inadequate for complete recovery. Exploration projects could be delayed for extended periods due to the loss of facilities (e.g., the Vehicle Assembly Building or an Ares launch pad unavailable for a year or more), and other NASA programs likely would have their budgets tapped to make up for funding shortages.

Man-Made Disasters

Industrial accidents or terrorist attacks may affect NASA programs whether or not they occur at or near NASA facilities. Large-scale physical damage or cyber-invasion could draw attention to vulnerabilities or safety problems at facilities supporting space projects, compelling those projects to divert resources and time to remedial actions. This would be especially likely if the incident had a

space-related cause, such as damage or injury resulting from a launch vehicle mishap or the uncontrolled de-orbit of a space object.

Expectations of terrorist threats, like weapons of mass destruction threats to the homeland, could result in requests from the Department of Homeland Security (DHS) or law enforcement agencies for NASA assistance. DHS is still in the early stages of determining how space systems and space-derived technologies can be applied to its mission. DHS will need to increase its sophistication in the use of remote sensing and geographic information systems. DHS is using unmanned aerial vehicles (UAVs) for border surveillance, so it is not unreasonable to anticipate increasing interest in satellite systems for similar purposes. For ground-based application of space technologies, DHS already has sought to tap into NASA expertise in robotics for use in hazardous environments and in sensors for detection of contraband at portals such as airports, seaports, and entrances to government facilities.[23]

Environmental Concerns

Global climate change fears, as well as regional and local environmental degradation, may rise in priority on the public agenda, fueled by circumstances such as:

- increased severe storm activity;
- other types of anomalous weather, especially related to temperature and precipitation;
- species extinction or unusual migration of species, including those known to be disease vectors such as insects;
- continued loss of polar ice and/or rise of sea level; and
- life-threatening pollution problems, especially affecting population centers and causing large-scale human migration.

Higher environmental priorities on the public agenda could be accompanied by a negative response to government space spending in areas other than Earth science, especially the expensive and visible area of human spaceflight. If environmental problems grow worse and public concern increases, NASA will be one of the first organizations the nation looks to for information and solutions. When that happens, there will be an expectation

that NASA has maintained its historic levels of activity and expertise in this area. If that turns out not to be true, the perception may be that the agency has sacrificed Earth sciences for the sake of Moon-Mars ambitions, to the detriment of down-to-Earth societal needs. Judging from congressional support for Earth science to date, legislators may prevent the situation from ever reaching this point. Future congresses may behave differently, however, allowing NASA to phase out this line of research. A backlash against this course of action will force Congress to mandate a return to greater visibility and funding for programs addressing environmental stewardship and remediation.

Pandemic

NASA does not have sector-specific responsibilities to aid the public in the event of an influenza outbreak or other disease pandemic. All federal agencies, however, are directed to "develop Federal implementation plans to include all components of the Federal Government and to address the full range of consequences of a pandemic . . .".[24] These consequences would certainly include disruption of the agency's work, possibly for an extended period. The Government Accountability Office has noted that, "an influenza pandemic would occur in multiple waves over a period of time, rather than as a discrete event. During the peak weeks of an outbreak of a severe influenza pandemic, an estimated 40% of the U.S. workforce may not be at work due to illness, the need to care for family members, or fear of infection."[25] Near-term operations obviously would be affected, but planning and execution of programs in the long term also could be undermined. Clearly, NASA's continuity of operations plan needs to take this into consideration. The agency can begin to address this by continuing development of its telecommuting and flexible work schedule programs—actions that can have benefits even in the absence of pandemic episodes.

Economic and Workforce Developments

Economic hardship can result from a number of conditions and have repercussions throughout many sectors of societal activity. Some examples include rising energy prices due to scarcity or

market manipulation; loss of export markets due to unfavorable currency exchange rates, deliberate resistance to American products, or war; natural disasters, pandemics, and global terrorism, which soak up resources, disrupt markets and supply lines, and hinder travel; and fiscal or monetary mismanagement at the national level. Economic downturns in the U.S. since the middle of the 20th century have been relatively brief and have not approached the severity of the Great Depression of the 1930s, but there is no guarantee that this will hold true throughout the decades that solar system exploration is building its momentum.[26]

Another challenge related to economics is more domestic in its focus: concern over the decline of the U.S. aerospace industrial base and workforce. Much has been written and debated on this topic in recent years,[27] so it will not be addressed here, except to note that there are worries in the space community that "loss of pre-eminence in our aerospace industry would certainly cripple our future and would foreclose on national capabilities."[28]

Sustaining Public Support

Spaceflight, especially involving human missions, is still perceived by many in the general public as an optional activity, not necessary for their survival or welfare.[29] One lesson to be drawn from the above discussion is that the space program needs to shed its image of being something "special" that involves occasional episodes of interesting and exciting activity. NASA and members of the space community have cultivated the "special" image over the years, but this is no longer fruitful and may invite competition from other national interests seeking to assert that space is no more "special" than they are. For space exploration and development to prosper over the long term, it must be widely perceived as a mainstream activity that benefits the national interest. This will require two things: continuous visibility and public education.

To achieve continuous visibility, NASA, with the help of the rest of the space community, needs to demonstrate scientific, technical, social, and economic benefits in its space exploration programs routinely. This will necessitate a broad definition of space exploration that includes not just human spaceflight, but anything that looks out beyond low Earth orbit, from orbiting telescopes like Hubble to robotic probes to planets and moons.

Research programs cannot always provide routine displays of progress on a preferred schedule, but a broad definition opens up more possibilities for associating benefits with the program.[30]

Some of the newsworthy opportunities that come along may not have the desired effect on policy-makers or the public, however. Timing and packaging must be approached with caution. For example:

- The results of the Exploration Systems Architecture Study (ESAS) were announced in a news conference by the NASA Administrator on 19 September 2005. Normally, this would have been an ideal opportunity to demonstrate progress in the program. The announcement came just three weeks after Hurricane Katrina devastated much of the Gulf Coast, however, with recovery costs already estimated by that time to be in the tens of billions of dollars. Nationwide news coverage of ESAS focused primarily on its $104 billion price tag, making NASA seem insensitive to recent events. Since most of the study's content had been previewed weeks earlier in trade publications such as *Space News* and *Aviation Week*, NASA would have been better off releasing the report without fanfare.
- The resemblance of the Crew Exploration Vehicle to the design of the Apollo capsule prompted the NASA Administrator to refer to the CEV as "Apollo on steroids." Catchy as this phrase may be, it sent two messages that did not reflect favorably on the program. First, it encouraged the perception that the program involves no new technology development, just the resurrection of a 40-year-old design, slightly enlarged. Second, steroids are associated most often with improper drug use, especially by young people– clearly not the image that NASA was trying to evoke.

The key theme of continuous public education should be that space exploration will be executed hand-in-hand with space development. The exploration component will make the program interesting and exciting, the development component will make it relevant and worthy of substantial investment. This is essential in answering legitimate questions from the public. Why do this? Why now? What is in it for me, for my country, for Earth?

An important consideration for public education is that the message does not need to be dominated by activities related to

human missions. The old saying in the space community, "they don't give ticker-tape parades to robots," ignores the changing reality. They don't give ticker-tape parades to astronauts anymore, but robots have websites that attract millions of hits. There are clear reasons for this new attitude:

- People born in the post-Apollo era grew up in a world of ubiquitous computers, at home and at school as well as in the workplace. This includes special-purpose computers embedded in toys, games, and household devices. They are also accustomed to the entertainment industry's depiction of robots as smart and capable. Personal identification with machines comes naturally to post-Apollo generations.
- Starting in the 1990s, NASA began to explore Mars with rovers instead of stationary landers. The mobility has been a boon to scientific investigations, but also may have profoundly changed the public perception of the missions in unexpected ways, especially among the younger, more technology-savvy population. A robot that moves around the surface of another planet generates a higher level of interest—and expectations for the future—compared to a robot that simply pans a camera platform from a fixed position.
- Robotic science missions and global climate studies may become increasingly popular if they are perceived to contribute to better environmental stewardship at a time of increasing concerns in this area.

Evolving public perceptions of robotic systems indicate that NASA should continue to emphasize the complementary nature of humans and robots on space missions, and go a step further as well. The centrality of robotics to the exploration architecture should be emphasized to a public that is eager to see technological advances coming from their tax dollars. The interested public can appreciate that the use of robots can help perform tasks more efficiently and safely, and in the long run may save some money on human systems. The public, especially its younger members, also has some expectation that robots will eventually proliferate the way computers have done, and space technology investment can accelerate this and give the U.S. robotics industry a competitive advantage in the world market.

The public's changing attitude on humans versus robots is not the only element of conventional wisdom that needs to be re-examined. Many in the space community, including NASA officials,[30] continue to repeat the dinosaurs-and-space myth, which goes something like this: all kids are fascinated by dinosaurs and space. Dinosaurs are part of the prehistoric past, while space is part of the present and future. Therefore, all kids are space enthusiasts who see space as an important part of their future.

There is no research indicating that the dinosaurs-and-space myth has ever been anything more than wishful thinking on the part of the space community. Polls related to the space program typically do not involve age groups under 18. Yet the conventional wisdom is that young children are space enthusiasts who lose interest somewhere between junior high and college for reasons that remain unclear. The underlying assumption may be faulty—the majority of American children may not be space enthusiasts, and the onset of puberty may have nothing to do with their continued interest in the subject.

In contrast to kids growing up in the Apollo era, young people today have many more information sources and distractions: 100-plus television channels, computers linked to the Internet at home and at school, cell phones and portable entertainment devices, and far more extracurricular activities at school than were common in previous generations. The downside of having access to this multitude of information sources is that misinformation has proliferated at least as much as accurate information—a fact of life for people of all ages, but more challenging for young people who lack the judgment to filter it properly.

It should also be recognized that interest in space-related fiction does not necessarily translate to support for NASA programs. Space entertainment—movies, television shows, websites, video games, science fiction books and periodicals—has enjoyed considerable popularity during the past three decades, but its avid followers may have little or no interest in real spaceflight and space science programs. To assume that this group is already on board would be a mistake. In any case, little is known about whether they are politically active, or would be inclined to become so.

Further study is required by polling organizations and specialists in elementary education to ensure that public education targeted at young children and their parents is carrying messages

that will be heard and internalized. As with adults, it may be a simple matter of maintaining continuous exposure to space-related achievements and information—something that appears to be lacking today. National space efforts will suffer if younger generations reach the politically active stage of their lives believing fallacies like, "we don't need weather satellites—we can just turn on the Weather Channel."

Going Beyond Technical Execution

Some members of the space community, opining on the sustainability of the exploration program, have said that all we need to do is execute. In other words, if NASA and its contractors deliver as advertised on cost, schedule, and performance, then sustained public and political support will result. This view ignores the big picture, which includes trends in public opinion, demographic shifts, the ramifications of adverse national and world events, and other hard-to-predict circumstances.

Space exploration must compete in a tough fiscal environment for a limited pool of public resources. Public investment in an expensive and highly visible civil space project like human space exploration may or may not yield quantifiable benefits adequate to justify the cost. If it does, those benefits are likely to be far in the future, widely dispersed, disassociated from their origin, and impossible to measure. Such a situation provides little incentive for policy-makers to invest their own political capital in fighting for these projects, and the taxpayers' resources in funding them. As a result, achieving long-term sustainability requires more than just getting the technical details right and requesting a sufficient annual NASA exploration budget. Current events, changing political and economic conditions, proliferation of space capabilities in other nations and the private sector, and a host of other factors combine to present a constantly shifting set of variables, requiring continuous forward thinking about non-technical considerations.

High-Risk Periods on the Horizon

Many of the sustainability risk factors described here cannot be predicted as to their timing and impact (e.g., geopolitical conflict,

natural and man-made disasters, major economic setbacks). However, three time periods over the next 12 to 15 years stand out as potentially very challenging to the exploration program due to the confluence of known events and decision points.

The three-year period from 2009 to 2011 will witness substantial changes in the political environment and critical decisions about the nation's future in space exploration. Some of the most important events are the following:

- A new president and Congress will take office. Civil space projects will be low on the agenda, and the new administration will not feel pride of authorship for the exploration program.
- Space shuttle flights will be discontinued, presumably having completed assembly of the ISS. NASA will be focused on the transition to the new space transportation system, and temporarily will be without independent human access to space. The only demonstration of human spaceflight hardware planned during this time will be an unmanned suborbital test of the Ares 1 booster. This relatively inactive period will be occurring at a time when as much as two-thirds of the agency's budget could be devoted to human exploration projects.
- The nation's new leadership will need to determine how much of the funding freed up from the shuttle and ISS programs should be used to support exploration or other NASA programs. This will coincide with decisions about the timing and scope of development programs for the cargo launcher and lunar infrastructure elements.
- The Centennial Challenges and Commercial Orbital Transportation Services (COTS) programs will have either started to deliver on their promises or failed to produce alternative technical solutions.
- The European Space Agency will hold a ministerial meeting in 2011 that is likely to make important decisions about Europe's goals, funding, and partnerships for exploration in the decade that follows.
- By this time, more should be known about the human spaceflight ambitions of other spacefaring nations, particularly China, India, and Russia, including how serious they are about their proposed schedules.

From 2011 to 2016, plans for the future of U.S. participation in the ISS must be finalized. If a decision is made to phase out ISS activity in this timeframe, several issues must be resolved:

- Will this still seem like a wise decision at that time, if foreign partners aboard ISS are demonstrating scientific or economic benefits as the U.S. walks away from the facility?
- Will policy-makers and the interested public feel that the U.S. has recouped its investment in the station by that time? If not, will they resent handing over operational control to the station partners?
- How will this hand-off be executed, and will the U.S. be able to return to the station if the need arises?
- What responsibilities will the U.S. have when it comes time to de-orbit or otherwise decommission the station?

Looking further out into the 2020s, the U.S. plans to return to the Moon and to begin establishing a sustainable lunar infrastructure. Some of the likely issues include:

- Private sector involvement and investment must be integral parts of the development of cislunar space. Legal and regulatory barriers (e.g., property rights, use of spectrum) and economic challenges must be addressed if viable business plans are to be in place by that time.
- It may prove difficult to sustain public interest and support during the slow build-up over several years to an operational lunar base. Policy-makers and the public may react as they did after the Apollo 11 landing: mission accomplished, no further action needed.

Options for Consideration by NASA's Exploration Programs

Although many of the challenges to long-term sustainability are unpredictable and beyond the control of the exploration program's managers, there are some actions ESMD can take to shore up support among the American public, decision-makers, and special-interest communities here and abroad.

- Portray space exploration and development as two sides of the same coin: As humanity moves out into the solar system,

benefits to Earth also will be forthcoming. Be as specific as possible about these benefits.

- Early buy-in from participant communities is essential to avoid concerns that may cause some to withhold support. The large number of potential participants, including various factions in science, engineering, and the private sector, indicates that a collaborative network across these communities is needed to keep all engaged and to solicit input that will help balance stakeholder interests without appearing to favor particular regions, institutions, or scientific disciplines.
- As foreign partners join the exploration architecture, establish their roles and responsibilities as soon as technically feasible. Offer partners program components that have challenging research and development content. Ensure that foreign partners receive due credit for successes in program milestones and spaceflight events.
- Planning for exploration architectures and timelines should consider the expressed interests of potential international partners and the opinions expressed in U.S. polls, which indicate that the return to the Moon should be for a long-term beneficial purpose, not just for a training stop on the way to Mars. There is substantial support for the scientific study of Mars by robots, but much less for human missions there.
- Do not underestimate the allure of robotic missions. Younger generations identify with robots much more readily than older generations. Emphasize the complementary nature of humans and robots on crewed missions and the centrality of robotics to the exploration architecture, rather than depicting robotic probes as mere precursors to human missions.
- When planning education and outreach programs for young people, challenge the conventional wisdom that all children start out as space enthusiasts and then lose interest for unknown reasons as they grow older. This has never been demonstrated with hard data, and it is more likely that most children lack interest or awareness in the first place.

Options for Consideration by NASA's Top Management

At the agency level, and in some cases in partnership with other U.S. agencies, there are actions that NASA can take to help ensure

the long-term sustainability of the exploration program.

- NASA should shed the space program's long-held image of being something "special"—providing occasional demonstrations of scientific and technological prowess that can be spectacular, but may be seen as an increasingly unaffordable luxury. The agency should strive to be perceived as a mainstream activity that directly benefits the national interest. This approach, emphasizing NASA as an essential investment in the nation's future, is necessary in an era where limited-duration space missions are giving way to unlimited-duration research, the building of infrastructure, and ongoing operations. Continuous public visibility, demonstrating scientific, technical, social, and economic benefits, is more important than occasional spectaculars. NASA should work to prevent the politically risky perception that it is a single-mission agency, which could severely limit its ability to build a constituency.
- NASA should support efforts to revise export control laws and regulations on space technology. This will enable more efficient and productive cooperation with international partners. It will also be necessary if technological spin-offs are to produce economic benefits, which will be severely curtailed if the technologies are not exportable.
- Private-sector involvement and investment, including that of non-aerospace companies, is essential to the long-term success of space exploration and development. NASA, along with other relevant U.S. agencies such as the Departments of Commerce, State, and Transportation, must work to establish an environment in which business cases for space development can be made to work. For example, the issue of property rights in space must be settled to the satisfaction of private-sector investors before lunar development begins. Serious efforts to resolve such issues should not be put off—resolution requires reconsideration of domestic and international law and therefore will take several years.

Conclusion

This article has discussed some formidable challenges to the long-term sustainability of human exploration of the solar system. To remain sustainable, this colossal effort must be relevant to societal

needs, able to deliver benefits worth the cost, and recognized for these characteristics by decision-makers and the public. This suggests that space exploration should go hand-in-hand with space development. Exploration brings excitement, intellectual stimulation, and for some, even spiritual fulfillment. Development brings relevance and the potential for societal benefits of great magnitude. Both are needed to maintain support throughout a long and difficult journey, providing answers to the question: why do it?

Notes

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4. James E. Webb and Robert McNamara, Memorandum for the Vice President, "Recommendations for the National Space Program: Changes, Policies, Goals," 8 May 1961. Reprinted in John M. Logsdon et al., *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume I, Organizing for Exploration* (Washington: NASA, 1995), SP-4407, p. 444.
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8. Richard Hall, "Participation, Abdication, and Representation in Congressional Committees," In *Congress Reconsidered*, L. Dodd and B. Oppenheimer, Eds. (Washington: Congressional Quarterly Press, 1993), pp. 161–187.
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13. The following is displayed under the heading *NASA Fact*: "In a Gallup poll, 68% of those surveyed support the new plan to return to the moon, then travel to Mars and beyond," http://www.nasa.gov/mission_pages/exploration/main/index.html, (accessed 22 February 2007).
14. "Gallup Poll Finds Americans Overall Strongly Support Space Exploration," *Space Daily*, 27 September 2006, (http://www.spacedaily.com/reports/Gallup_Poll_Finds_Americans_Overall_Strongly_Support_Space_Exploration_999.html, accessed 27 September 2006).
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16. Mary Lynne Dittmar, "Engaging the 18–25 Generation: Educational Outreach, Interactive Technologies, and Space". Briefed to the Workshop on Building and Maintaining the Constituency for Long-Term Space Exploration at George Mason University, Fairfax, VA, 1 August 2006 (Dittmar Associates Inc., Houston, Texas, 2006).
17. *The Harris Poll* #30, "Closing the Budget Deficit: U.S. Adults Strongly Resist Raising Any Taxes Except 'Sin Taxes' Or Cutting Major Programs," 10 April 2007. Other federal programs (and percent of respondents choosing them) were welfare programs (28%), defense spending (28%), farm subsidies (24%), environmental programs (16%), homeland security (12%), transportation (11%), Medicaid (4%), education (3%), Social Security (2%), and Medicare (1%). (http://www.harrisinteractive.com/harris_poll/printerfriend/index.asp?PID = 746, cited 4 May 2007).
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24. Homeland Security Council, "National Strategy for Pandemic Influenza: Implementation Plan," May 2006, p. 178.
25. U.S. Government Accountability Office, "Influenza Pandemic: DOD Has Taken Important Actions to Prepare, but Accountability, Funding, and Communications Need to be Clearer and Focused Department wide," September 2006.
26. For an excellent discussion of current global economic threats such as currency and debt crises, problems with the global reserve system, and unsustainable trade agreements – and why we should not be complacent about our ability to manage them—see Joseph E. Stiglitz, *Making Globalization Work* (New York: W.W. Norton & Company, 2006).
27. For example, see Booz-Allen & Hamilton, "U.S. Defense Industry Under Siege—An Agenda for Change," 2000; James W. Canan, "The Changing Defense Industrial Base," *Aerospace America*, August 2006, pp. 34–38; Robert J. Kuntz, "Aerospace Needs Knowledge-Management Tools," *Aviation Week & Space Technology*, 3 September 2007, p. 74.
28. Jefferson Morris, "Northrop Grumman CEO Sugar stresses importance of space exploration," *Aerospace Daily & Defense Report* 216:29, (10 November 2005).
29. For example, see *Harris Poll*, "Closing the Budget Deficit," 10 April 2007. which implies that approximately half of the U.S. voting-age population, views the civil space program as either a waste of resources or simply a non-essential activity.
30. NASA had a very good media week in early December 2006 that demonstrated how positive exposure across programs can work. Three events got front-page coverage on the dates shown: the announcement of the lunar base plan (Dec. 5), the publication of research indicating flowing water on Mars (Dec. 7), and the first post-*Columbia* nighttime shuttle launch (Dec. 10). This was not a "slow news" week in other areas—for example, the long-anticipated Iraq Study Group report was released at this time. The NASA stories, as presented in the *Washington Post*, were as follows: Marc Kaufman, "NASA Plans Lunar Outpost; Permanent Base at Moon's South Pole Envisioned by 2024," Tuesday, Dec. 5, page A01, above the fold; Rick Weiss, "Mars Photos May Indicate the Recent Flow of Water," Thursday, Dec. 7, page A01, above the fold; "Discovery's Spectacular Show," picture with caption, page A01, referring to story on page A20.
31. For example, Scott Horowitz, NASA Associate Administrator for Exploration Systems, speech at a Capitol Hill luncheon sponsored by the Coalition for Space Exploration, 14 September 2006.