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Odyssey: Principles for enduring space exploration

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Abstract

As the USA, Europe and other nations embark on a new voyage of exploration to the Moon, Mars and beyond, they should lay the foundations and establish precedents that invite a host of participants and followers. We argue that international cooperation, driven by foreign-policy and cost-sharing considerations, has taken a prominent role but must be pragmatically and flexibly balanced with economic and strategic self-interest. Since exploration visions are likely to differ, the steps each country will pursue, the funding provided, and schedules followed will also differ. To support an enduring exploration vision, it will be important to remain flexible to changing priorities and amenable to the inclusion of new, non-traditional participants. Open-systems principles and *metaprinciples* should be employed at all levels—hardware, software, programmatic, political and cultural. Equally important, national leadership and decision makers should be mindful of the potential pitfalls that might undermine the venture. While the new vision inspires us all, it will take creativity, resourcefulness, hard work and cooperation to succeed.

1. Introduction

Humankind is embarking on a great odyssey: the migration of the Earth's peoples and cultures to other worlds. The recent catalyst for this movement is President George W. Bush's bold redirection of the USA's civilian space program to pursue exploration to the Moon, Mars and the "worlds beyond".[1] First announced in January 2004, and now endorsed by funding from the Congress of the USA, the Vision for Space Exploration charts a bold course for America's National Aeronautics and Space Administration (NASA), its industrial sector and its citizens. It also invites participation by other nations "to share the challenges and opportunities of this new era of discovery".

Other spacefaring nations, we should point out, were not waiting idly by—they were in fact developing exploration visions and programs focusing also on the Moon and Mars. On 15 October 2003, China began its human-spaceflight program with the inaugural launch of Shenzhou-5, becoming the third nation to develop a human-spaceflight capability. Russian space experts began designing the Kliper spaceship in 2001—a follow-on vehicle to replace their venerable Soyuz in servicing the International Space Station (ISS), but with increased crew capacity and serviceability. In 2001 the European Space Agency (ESA) laid the groundwork for their future space exploration plans in the Aurora Project, with a focus on robotic exploration of Mars followed by eventual participation in human exploration. While most spacefaring nations still have their fiscal investments firmly anchored in the ISS program, it is clear that, even by January 2003, a year before President Bush's announcement, they were already eager to escape the bounds of Earth orbit.

The US Vision for Space Exploration did not evolve as the next logical step in a methodical US approach to space exploration and discovery. In some sense it is the latest in a series of desultory attempts to provide a justifiable purpose for spending $15 billion dollars annually on the US civil space program administered by NASA. In the early months of the George W. Bush administration a leading

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[1]President George W. Bush, Vision for Space Exploration speech, NASA Headquarters, January 14, 2004. Accessed at http://www.whitehouse.gov/news/releases/2004/01/20040114-3.html.

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space expert met senior White House officials to discuss the options for addressing NASA's cost overruns on the ISS—a problem of major concern in 2001. It was suggested by the expert that reassessing the costs and missions of the ISS was an opportunity to pursue a more fruitful and strategic vision for the space program. The White House official had no interest in doing so, simply getting the ISS costs in line was perceived as sufficient.[2] That is, until disaster struck. When the Space Shuttle *Columbia* disintegrated in the skies over Texas on 1 February 2003, NASA, the White House, the Congress, and the American people were forced to address the shortcomings of a dubious space program marooned in low-Earth orbit.[3]

The *Columbia* accident had a tremendous effect on the US civil space program, leading to a complete reassessment of the US national space policy and to dramatic changes at NASA. In the context of the subsequent Columbia Accident Investigation Board report,[4] President Bush announced a new vision for human and robotic space exploration for NASA on 14 January 2004 (see footnote 1). President Bush called for redirecting NASA's human exploration program from low-Earth orbit to the Moon, Mars and "worlds beyond". Achieving that goal would involve both robotic and human missions. According to the president's speech, humans would return to the Moon in 2015–2020 and eventually go to Mars (no date given). The Space Shuttle program would be terminated by 2010 when construction of the ISS was to be completed. President Bush reassured ISS partners that the USA would meet its obligations and also invited other countries to join the USA in the Vision.

Despite the fiscal obstacles of human space exploration, it is important to understand the magnitude of this new adventure. Mankind is on the threshold of stepping off into space and onto other worlds to stay. In the words of Konstantin Tsiolkovsky, "Earth is the cradle of humanity, but one cannot remain in the cradle forever". This exploration will soon expand beyond the scope of initial lunar and Martian survey missions modeled after the 19th century Lewis and Clarke expedition in North America. How these first steps are taken will determine the pace of expansion—whether this journey begins as the sport of kings or as a highway for all will depend on how the nations of the world structure their national space programs, join together in cooperation, and enable their private sectors and citizens to follow.

We propose that open-system architecture approaches will be valuable in sorting out the myriad programmatic approaches. What are the best technical solutions for space exploration transportation systems? What important activities do we plan to pursue on the Moon and Mars? How much international cooperation to pursue? How much private sector participation to allow? When do partners enter into long-term programs or short-term projects? The discussion that follows focuses largely on examples and issues most familiar to the authors and thus represents decidedly American and European perspectives. Nonetheless, we believe the open-systems principles will apply equally well to participation by other spacefaring nations, now and in the future. As more nations enter the ranks of spacefaring powers, there will be new opportunities for cooperation along with attendant concerns about security, economic and cultural issues. An open-systems approach provides a flexible way to leverage cooperative opportunities between existing partners today without precluding new opportunities in a changing geopolitical future.

2. Exploration beyond earth orbit

In this paper the authors wish to define a broader concept of exploration, enumerating its multifaceted aspects of science, commerce and culture. While the Apollo program in the 1960s achieved the first human landing on another world, it did not establish a sustained presence. This is not to belittle the accomplishment but to point out that these new exploration efforts attempt to establish an enduring human presence on other worlds. This journey will not be solely about prestige or science, the traditional goals of space missions; it will also seek to establish a presence and the supporting infrastructure to support commercial and cultural objectives as well.

This new US space exploration policy calls for "a sustained and affordable human and robotic program to explore the solar system and beyond" and seeks also to "promote international and commercial participation in space exploration to further US scientific, security, and economic interests". The expense of such ambitious goals could prove to be enormous.[5] In this context the participation and cooperation of other major spacefaring nations is an important asset for such an endeavor. This plan poses both a challenge and an opportunity to all other

[2]Personal communications by the author (RRC) with an official from the White House Office of Management and Budget (later to become a senior official at NASA) in 2001.

[3]Personal communications by the author (RRC) with an official from the White House Office of Science and Technology Policy in 2004. The official explained that the impetus for the Vision for Space Exploration was to respond to the Columbia disaster. The officials further explained, somewhat surprisingly in this author's opinion, that China's incipient manned-space effort was not a factor.

[4]Columbia Accident Investigation Board, Report Volume 1, p 209, August 26, 2003. The report included the first public recognition from an officially established committee of a fairly obvious situation: "…the lack, over the past three decades, of any national mandate providing NASA a compelling mission requiring human presence in space."

[5]Congressional Budget Office (CBO) Study: "A Budgetary Analysis of NASA's New Vision for Space Exploration", September 2004. As underlined by the CBO study assessing NASA's future exploration programs and the funding that might be needed to execute them, NASA will face a number of significant technical hurdles notwithstanding NASA's previous experience with the Apollo program and its robotic missions to other planets. Even assuming international cooperation on completion of the ISS and participation in exploration, the CBO study found that NASA would have difficulty affording the Vision for Space Exploration.

potential partners. Other nations, particularly the ISS partners, have made ISS utilization the centerpiece of their planning for the next decade and beyond. Now they are being asked to join the USA in another new project while they continue their plans for ISS utilization.

On the other hand, the Vision for Space Exploration could benefit from the experience of international partners in the ISS framework. While the Vision for Space Exploration is a worthy goal, it is not yet certain that the USA will sustain its pursuit. This fact should elicit circumspect responses from potential international partners. The important question arises: how to manage these potential cooperative activities in a way that benefits all partners and minimizes risky dependencies that might threaten the autonomy of various partners? An important part of the answer to that question should include the principles of open-system architectures.

3. Cooperation in space activities

Recent geopolitical developments, combined with the funding constraints of the various spacefaring countries, have made it clear that greater international cooperation will be important for major space activities.

Cooperation is recognized as a central element of overall foreign-policy objectives such as expressed in the 2002 National Security Strategy of the USA, both with the world at large and with its traditional allies:

> America will implement its strategies by organizing coalitions—as broad as practicable—of states able and willing to promote a balance of power that favors freedom. Effective coalition leadership requires clear priorities, an appreciation of others' interests, and consistent consultations among partners with a spirit of humility.
>
> There is little of lasting consequence that the United States can accomplish in the World without the sustained cooperation of its allies and friends in Canada and Europe.[6]

Following foreign policy, cooperation is now an integral part of the space policy of the different agencies around the world and nations no longer initiate and carry out a significant space program without some element of foreign participation.[7] Cooperation gives them the opportunity to rationalize and optimize their planning and resources by coordinating the development of their respective missions; it also enlarges the spectrum of mission possibilities. Nations cooperate on space activities when it benefits their self-interests. Partners may be pursuing common programmatic goals, but for different reasons.[8,9]

Civil missions carried out on a purely national basis are more and more a thing of the past, certainly in terms of the utilization of the data acquired and the exploitation of the results.[10] International cooperation expands the scope of programs beyond the individual participants' capabilities. This expansion of resources available through cooperation is not just financial, but also scientific and technological.

At the same time interdependence can affect successful budget and schedule performance. International partners can also serve to enhance the legitimacy and credibility of a venture thus strengthening political and financial support and conferring greater stability. However, it is well recognized that international cooperation adds layers of complexity to the design and management of programs (see footnote 8).

The arguments in favor of cooperation have not fundamentally changed since the beginning of Space Age; they are still political, scientific and economic. But the nature and scope of international cooperation in space has fundamentally changed in recent years, leading to a new paradigm in international space activities. First, the number of countries that could contribute to these cooperative endeavors has increased. Second, the end of the Cold War removed the 50-year East–West barrier and new perspectives for cooperation are arising. Third, cooperation is not only restricted to short-term programs but has evolved to more strategic and long-term agreements, as illustrated by the multi-year science projects Hubble and Cassini–Huygens. Fourth, the USA and Russia are no longer the only nations that can lead cooperative projects. There are now numerous players with varying degrees of capability allowing them to cooperate while providing a technological benefit.

Thus the nature of international cooperation in space is fundamentally changing. There is an evolution in the hierarchy of space actors since the early days when the USA, Europe, Russia and Japan cooperated in the Halley's Comet missions. The recent achievements of India and China have lead to a new multipolar era with multiple nations having varying degrees of capability. Cooperation is becoming a central strategy for realizing technical and strategic aims. The number of potential partners with sophisticated government and industrial space technologies and capabilities has grown, and the majority of spacefaring nations have much more experience in working together in their space programs (see footnote 8).

[6]The National Security Strategy of the United States of America, p. 25, September 2002.

[7]Randall R. Correll, "Military Space Cooperation: Aligning the balance of power and building common interest". *Astropolitics* 2004; **2**: 133–147.

[8]Report of the AIAA International Activities Committee Workshop, "International Space Cooperation: From Challenges to Solutions", American Institute of Aeronautics and Astronautics, May 2004.

[9]Peggy Finarelli and Ian Pryke "Optimizing Space Exploration through International Cooperation", 1st Space Exploration Conference: Continuing the Voyage of Discovery, Orlando, FL USA, 30 January–1st February, 2005.

[10]Ferrazzani Marco, "Alternative Approaches to International Space Cooperation", ESA Bulletin 110, May 2002.

This multiplication of spacefaring countries with varying ranges of capabilities leads to an increase in cooperative possibilities that allow space agencies to cooperate *à la carte*, rather than using the prior cold-war-era set menu. With this multiplication of international cooperation in space activities, various forms and mechanisms of cooperation have flourished.

NASA managers are rapidly exploring old and new paradigms for programmatic approaches. Some approaches initiated in the first months after the vision was announced have already been abandoned, such as plans for detailed technology and capability roadmaps originally recommended by the President's Commission on Implementation for the United States Space Exploration Policy.[11] Also suddenly abandoned were plans for government-enabled industrial teaming, such as in the Joint Strike Fighter program which was adopted by NASA for the Crew Exploration Vehicle (CEV) project.[12] The latest plans for the CEV and Crew Launch Vehicle (CLV), not yet official at the time of this writing, reportedly resemble a dedicated national program—essentially the Apollo program approach.[13] For the USA at this time, the central capability of crew launch and transport may require this approach. When and where other nations will be allowed to join this embryonic exploration architecture is entirely unknown.

4. Multipolar space powers

In part because of its long-standing position as the leader in space technology, the USA has been slow to recognize and respond to foreign advances,[14] and is no longer in concordance with the global space context and its traditional partners' aspirations. The emergence of foreign competition and alliances presents both a challenge and an opportunity to the USA. NASA's achievements and dominant role in space activities explain its typical approach to international cooperation—it first defines its mission objectives and content, and then invites other countries to participate. However, in a multipolar world, such a unilateral approach might not be a viable model in dealing with global science projects, especially in the case of ambitious exploration goals and concurrent budget constraints.

Major space programs are mutually dependent as a result of increasing international cooperation. The USA needs to accept this mutual dependency at some level, and it should strive to be a reliable partner through faithfulness to long-term commitments and adherence to international agreements. It must admit that the defense of its 'leadership' is not necessarily an objective of great appeal to its partners. The leadership role must be earned—not by resting on past achievements nor by unilaterally establishing the architecture, but by putting in place a program and architecture that allow for partners to participate in significant ways. The USA needs to change its current practices if it wants to continue to remain a world leader with great ambitions. It should also understand that it may lead and sometimes not; that other countries have matured and might be able to provide leadership of their own.

For instance, Planetary Exploration is not new to ESA. Not only has ESA successfully flown missions to Mars, the Moon, a comet, Titan, Saturn and soon Venus, it also has significant experience in human spaceflight, currently focused on the ISS. Furthermore, ESA initiated the Aurora program in 2001 to formulate and implement "a European long-term plan for the robotic and human exploration of solar system bodies holding promise for traces of life".[15] It is a decades-long program featuring multiple robotic missions to the Moon and Mars, a Mars sample-return attempt and, ultimately, astronauts to the Moon and Mars. Germany's recent decision to join Europe's space exploration activities testifies to the growing interest in space exploration in Europe. However, Europe now has to decide whether or not it wants to join the US exploration program, and how.

The Vision for Space Exploration will benefit from international cooperation being sustainable, flexible and robust. In this context, European participation can be a critical enabler for the US program, since going to the Moon, Mars and beyond will not be the journey of a single country. However, before Europe agrees to significant cooperation in the Vision for Space Exploration, concerns with respect to the future of the Space Shuttle and the ISS have to be addressed. Europe will probably not enter into another partnership with the USA if such a partnership is not based on a solid and equitable foundation. In this regard there needs to be an increased level of discussion between Europe and the USA.

[11]Report of the President's Commission on Implementation for the United States Space Exploration Policy, June 2004, "A Journey to Inspire, Innovate, and Discover, accessed on the Internet at http://www.nasa.gov/missions/solarsystem/explore_main.html. The new NASA administrator, Dr. Michael Griffin, recognized that the roadmapping activity, which his predecessor at NASA had initiated, did not provide timely information regarding important programmatic and budgetary decisions.

[12]In his testimony to the Congressional Committee on Science, United States House of Representatives, June 28, 2005, The NASA administrator, Dr. Griffin, announced that NASA had begun a 90-day Exploration Systems Architecture Study to inform the urgent programmatic and budgetary decision. Accessed at http://www.house.gov/science/hearings/full05/june28/griffin.pdf

[13]The anticipated exploration transportation system is nearly identical to the system outlined in "Extending Human Presence into the Solar System", The Planetary Society, July 2004. This was an independent study co-chaired by Michael Griffin and Owen K. Garriott. The system described therein is based on shuttle-derived hardware for ferrying astronauts to and from the ISS, the Moon, and eventually Mars. Accessed at http://www.planetary.org/aimformars/study-report.pdf

[14]Joan Johnson-Freese: "Changing patterns of International Cooperation in Space", Orbit Book Company. 1990.

[15]Aurora Exploration Programme mission statement. Accessed at http://www.esa.int/SPECIALS/Aurora/ESA9LZPV16D_0.html

5. Principles of open-system architectures

Several different approaches to organizing cooperative space activities have already been tried, and it is very likely that new approaches will emerge, since cooperation can occur at different stages of a space project (mission planning, mission design or mission operations, etc.), each requiring different organizational structures. For the new space exploration vision, which is fundamentally different from previous large space ventures including the ISS, a new structure of cooperation will be needed. To develop this, we argue for applying the principles of open-systems architectures.

The most well-known example of open-systems architecture is the internet. This system uses published standards and communications interfaces, is modular in terms of hardware and software, and is extensible almost without limit in terms of technology and content. The ISS is a space system that exhibits certain aspects of open-systems architectures: the docking interfaces are standardized so that the participating nations can build laboratory modules and re-supply vehicles compatible with the interface.

5.1. Metaprinciples

The internet and the ISS are examples of hardware and software interfaces of physical systems. We would like to expand the notion of open-systems to a broader context. Enduring exploration architectures require openness to interaction between the various sectors and participants, such as national interests, the scientific community, commercial interests, the general public and the private sector. We will need *metaprinciples* for architectures that reside above the traditional systems engineering and integration layers of hardware and software. These metaprinciples would allow for the incorporation of activities such as space tourism—that is, privately sponsored spaceflight—in otherwise government-only programs. The lack of such a metaprinciple for cooperation on ISS is what led to the discord between entrepreneurial private citizens teaming with the Russian space program to promote space tourism, on the one hand and NASA's bureaucracy, on the other.[16]

5.2. Architectures and systems

An important concept for open-systems architectures is that they be collaborative in nature. Collaborative system-of-systems models are comprised of system elements that (1) have operational independence, (2) have management independence, and (3) most importantly, lead to emergent properties.[17] The objective of open-systems architectures is to enable growth in participation and in functionality. Most space missions are closed systems defined solely to serve a dedicated function or to complete a dedicated mission for a limited amount of time, generally in the order of few years. The Apollo lunar program was such a mission. The ISS significantly opened its architecture to enable increased participation and functionality through the addition of modules via standardized docking interfaces. The process for approval to access the ISS architecture, on the contrary, is rather less open, being composed of a complex set of international agreements binding the partners.

The open-systems architecture for space exploration must be defined in a way that continuously allows for and enables increased participation and functionality. These architectures will consist of dedicated missions, bases and laboratories on the moon and Mars working in concert with infrastructure such as communications, navigation, remote sensing satellites, and transportation services. Who will pay for the infrastructure? Who will benefit from it? Who will be allowed to access the communications systems? Will the protocols and standards be freely published? Will private interests be allowed to add a commercial module to a government-owned lunar base? Thus, along with the technical issues involved, the metaprinciples of the architectures will need to be addressed in advance.

Open, collaborative architectures require the integrated system to fluidly accept the integration or loss of various subsystems with minimal system degradation. This provides robustness to the architect. Architectures should be devoid of any single point failures, and any system or process that affects critical paths of the architecture should be judiciously scrutinized. The system not only needs to be integrated vertically, such as within a government-sponsored mission to the Moon or Mars, but it should be open to integration horizontally, e.g. through the open participation of other nations' civil programs and of commercial entities. In the context of a three-decade long initiative such as an eventual human mission to Mars, the geopolitical situation will evolve dramatically, and new spacefaring nations or non-state actors will be eager to participate, contribute and benefit, so a flexible mechanism should be put in place to allow such evolution. The plug-and-play approach from the information technology industry should be adopted here.

[16]Dennis Tito, in collaboration with the Russian Space Agency, became the world's first space tourist despite the controversy with NASA over Mr. Tito's presence on the ISS. A representative press report on the issues can be accessed at http://news.bbc.co.uk/2/hi/science/nature/1315214.stm

[17]Mark Maier, "Clean Sheet Design of an SE&I Structure Based on Existing Government (NASA) and Industrial Institutions", ESMD Systems Engineering and Integration Workshop, December 15–16, 2004. Accessed at http://exploration.nasa.gov/documents/reports/SoSEI_12-2004/

5.3. Flexible decision making

Open-systems considerations also apply to decision making. Most importantly, decisions made today should minimally constrain decisions in the future. This is an important point to be considered regarding fiscal investments by the participants. In periods of limited public funding, it is of paramount importance to avoid duplication of effort, to enhance the complementary roles of various partners, to fill capability shortfalls, and to leverage the private sector. Architectures should be pursued that allow flexibility to commit investments in a modular fashion. Multi-decadal cooperative commitments on specific systems should be entered into with circumspection.

This point is not to be taken to the extreme case in which cooperative commitments are avoided entirely. There is enormous fiscal benefit for partners sharing the cost of a major integrated space system. The ISS is a case in point. However, all parties must recognize that there is a variety of risks involved: some technical, some political. If one partner delays in delivering a critical element, all partners will incur unexpected costs because of the delays. There is also the possibility that a partner may change priorities and discontinue funding of the cooperative activity. The extent to which partnering nations have the authority to make long-term goals depends on the particular details of the political process within each sovereign nation. In fact, for each nation intent on international cooperation, it is of the utmost importance that it first understands the limits of its own authority in pursuing long-term agreements.

Political uncertainties aside, long-term programmatic commitments inhibit the ability to redirect exploration priorities in the future based on new knowledge. For example, an architecture focused on searching for past life on Mars would be significantly redirected if extant life were discovered there.[18] Not only will interests change, but so will concerns, such as biological contamination, the sustainability of long-duration visits to habitation modules, commercial interests, and property rights on the Moon and Mars.

As mentioned above, several different approaches to organizing cooperative space activities have already been tried, and it is very likely that new approaches will emerge in the near future, since cooperation can occur at different stages of a space project, each requiring different organizational structures and involving new participants. International space exploration as now envisioned will exceed the scale even of the ISS, and therefore new structures of cooperation will be needed. As a first step, a high-level discussion between Europe and the USA should be proposed to identify where the USA's Vision for Space Exploration and Europe's Aurora program overlap, and where they could be merged if required and wanted. This space exploration coordinating structure could later take into account partners such as Russia, India, Japan, China and other nations, possibly evolving to the formation of an 'International Space Exploration Coordination Council' as suggested by Finarelli and Pryke.[19] The emphasis of the coordination council would be to facilitate the discussion and planning of cooperative activities without imposing a controlling bureaucracy.

6. Potential pitfalls

With his re-election to a second term, US President Bush secured another four years to get his Vision for Space Exploration off to a solid start. Nonetheless, the multi-decadal space exploration strategy laid out in January 2004 still faces considerable challenges. One is convincing the Congress to continually approve the funding that NASA is seeking to complete the effort. Another challenge is to convince various international partners, and especially Europe, to join this Vision for Space Exploration, since a successful agreement on the future direction of the ISS is the prerequisite to any significant European participation in this program. Additionally, the vision will require the support of many newly elected administrations and Congresses in the ensuing years. Structuring a program with enduring support will be a challenge, and many potential pitfalls lie ahead.

6.1. Lack of compelling purpose

The most debilitating obstacle would be lack of compelling purpose. The human instinct to explore is, in itself, not sufficient to justify the public treasure that will be required. Neither is scientific gain, in itself, commensurate with the anticipated cost of publicly funded human space flight. NASA has not yet articulated how it will develop the objectives and purpose of lunar and Martian missions, laboratories, observatories and bases. Many of these decisions do not need to be made immediately and, following the metaprinciples of open-systems architectures, should not be forced prematurely. However, the process should begin among NASA, academia, industry, the public and the international community to debate the specific activities that will define the content of the program. Without visible progress in the development of compelling purpose, the exploration vision is not likely to endure, nor should it.

6.2. Inadequate funding

Space programs are expensive and complex, and cost overruns and schedule delays are to be expected. Schedule delays are less of a concern in that, in the words of

[18] "Methane on Mars causes controversy". Accessed at http://www.newscientist.com/article.ns?id = dn6425.

[19] Peggy Finarelli and Ian Pryke, 'A new paradigm for international cooperation in space exploration', *Space Policy*, 21(2): 97–99. See also footnote 8.

President Bush, we are beginning a "journey, not a race". Cost overruns, on the other hand, will add considerable risk to the success of the program. To mitigate this risk, NASA will need to invoke engineering and development rigor and leverage international and private sector participation (see footnote 5). Because of budgetary pressures inherent in space programs and currently within the USA to prosecute the war on terrorism, it is obvious that NASA needs to cooperate in order to achieve its goals and to bolster domestic political support. If the USA wants to complete this journey it should seriously consider international participation.

6.3. Existing programs

Future cooperation on exploration will also depend on the direction that the ISS program takes. The new US space exploration policy reaffirms existing commitments, but the Europeans would like to know what the USA's plans are after the assembly of the ISS, especially considering the retirement of the Space Shuttle. Moreover, the ability of European partners to benefit from their contribution to the station is dependent on how the USA fulfills its commitments to the ISS partnership. There are consequences to the delays in the assembly sequence of the ISS for the Europeans, since they are dependent on the Space Shuttle for the launch of their contribution, the Columbus Module. The launch date for Europe's contribution has shifted by at least two years from the planned October 2004 date because of delays in the return to flight of the Space Shuttle fleet. The USA and Europe reaching an acceptable level of completion of the ISS will determine how willing Europe will be to enter into new commitments on the Vision for Space Exploration.

On the other hand, the cost to complete and operate the ISS may undermine efforts to invest in lunar and Martian exploration. The most present danger is that NASA's CEV and CLV will be optimized primarily to service the ISS in the Space Shuttle's stead and would be inadequate to enable lunar exploration. It should be remembered that the Space Shuttle itself was expected to provide routine, low-cost access to space. But significant technical and programmatic difficulties encountered during development led to significantly reduced capability. The USA was then committed to operating the Space Shuttle at great expense for decades. If the CEV/CLV system is merely Space Shuttle *redux*,[20] the Vision for Space Exploration may be postponed indefinitely.

6.4. Faux partnering

Partnership needs to be real and substantive to be effective. The June 2004 recommendations of the President's Commission on Implementation of United States Space Exploration Policy accentuated a US-centric position (see footnote 11). The commission recommended that "NASA pursue international partnerships based upon an architecture that would encourage global investment in support of the vision". The narrative of the report clarifies that the USA must also "determine its own requirements, expectations, milestones, and risks" and "what part of its national industrial base it must protect," and only then indicate what it is "willing to cede" to potential international partners. These will be difficult concerns to balance. The commission identified two approaches to international cooperation that could be used to fulfill the Vision's objectives. The first approach is based on pooling resources and maintaining clean divisions in systems, tasks and responsibilities based on the ISS model. The other approach is based on the Joint Strike Fighter program. Both models put forward were perceived by international partners as inadequate. It is important that truly cooperative multilateral approaches be proposed. Following the metaprinciples, these do not have to span the entire scope of exploration, but they should address significant and substantive contributions and benefits for all participants.

6.5. Technology export restrictions

Current US export control policies often serve as obstacles to cooperation by preventing the open sharing of technology. Export controls have been placed on a wide range of technology needed for space activities. While export control for non-proliferation purposes is understandable, overly burdensome export control constrains international cooperation by creating administrative delays or by simply precluding such cooperation altogether.

The USA's International Traffic in Arms Regulations (ITAR) legislation has had a significant adverse impact on the USA's industrial competitiveness, since ITAR defines many commercial, dual-use space technologies as munitions. To avoid intransigent ITAR negotiations with US technology suppliers and partners, European companies have recently developed an ITAR-free platform by replacing US technology with foreign equivalents. Extrapolating this trend into the future, Europe and other spacefaring nations may have neither the desire nor the need to cooperate with the USA in space exploration. This fate would essentially fragment the resources of the spacefaring nations into two competing factions. Indeed, NASA has already declined to partner on the ESA ExoMars robotic mission, citing ITAR restrictions precluding the export of

[20] It is clear from previous publications that the newly appointed NASA administrator, Dr. Michael Griffin, is inclined to propose an 'Apollo-style' transportation architecture in order to leverage space-shuttle-derived hardware and infrastructure (see footnote 13). There are justifiable reasons for doing so and also great programmatic risks. One wonders if Dr. Griffin's nomination to the position of administrator was so well-received by the U.S. Congress because they had been assured that existing infrastructure and jobs would be protected. Without being able to divest

(*footnote continued*)
from some established activities, the exploration vision will require significant increase in NASA's annual budget.

entry, descent and landing systems.[21] The USA should re-evaluate the benefits of isolating its technology base from the global market versus the cost of the impact this will have on space exploration in particular and its industrial competitiveness in general.

6.6. *Uncertain geopolitical future*

Over the next 15 years before humans return to the Moon, the geopolitical context might be as different as it was 15 years ago.[22] This could prove very disruptive for space exploration by diverting resources to more pressing security needs and by unsettling the alliances needed to sustain multi-decadal projects. Therefore, to have a sustainable exploration initiative it has to be flexible and open to geopolitical evolution. The emergence of China and India as global powers, as well as other nations as new regional powers, will transform the geopolitical landscape as much as did the ascent of the USA in the 20th century. Notwithstanding the security and economic challenges of the future, the proliferation of space power will help sustain space exploration as long as these new actors can seamlessly connect into the ongoing open architectures. Despite the vicissitudes of national powers waxing and waning, the benefit of exploration to humankind will always be on the ascendant.

7. Summary

As the USA, Europe and other nations embark on a new voyage of exploration to the Moon, Mars and beyond, they should lay the foundations and establish precedents that invite a host of participants and followers. This broad view of exploration includes robotic and human missions for the purposes of science, commerce and culture. International cooperation, driven by foreign-policy and cost-sharing considerations, has taken a prominent role, but must be pragmatically and flexibly balanced with economic and strategic self-interest. Since exploration visions are likely to differ, the steps each country will pursue, the funding provided, and schedules followed will also differ. Some nations may pursue key elements of exploration architectures for strategic reasons, while other projects, missions and infrastructure may be readily composed of contributions from cooperating nations, industry and private interests. To support an enduring exploration vision, it will be important to remain flexible to changing priorities and amenable to inclusion of new, non-traditional participants. It is hoped that the private sector will invest in the exploration vision, expanding it in size and scope beyond the realm of national programs and allowing private citizens to participate. Open-systems principles and *meta-principles* will be important in making the vision a reality and should be employed at all levels—hardware, software, programmatic, political and cultural. Equally importantly, national leadership and decision makers should be mindful of the potential pitfalls that might undermine the venture. Cost overruns, schedule delays and entrenched interests of the past will be constant considerations. While the new vision inspires us all, it will take creativity, resourcefulness, hard work and cooperation to succeed.

[21] Peter B. de Selding, "German Involvement Crucial for ESA's ExoMars Project", Space News, p. 4, July 18, 2005.

[22] "Mapping the Global Future", Report of the National Intelligence Council's (NIC) 2020 Project, December 2004. As indicated in the NIC report, "at no time since the formation of the Western alliance system in 1949 have the shape and nature of international alignments been in such as state of flux". The end of the Cold War shifted the tectonic plates, but the repercussions from these momentous events are still unfolding. Other significant characteristics include the rise of new powers such as China and India.