"Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration"

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Input to this Presentation…

- Top level findings of the NRC Human Spaceflight Committee, as presented in the "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration"
- Consultations with other members of the Committee
- Discussions with Congressional staff who wrote the original authorization language directing the study
- Personal observations
- Discussions with NASA officials

The “Pathways Report”: Background

- The study was requested by Congress: 2010 NASA Authorization Act after the political upheaval stemming from cancellation of the Constellation program
- The committee addressed a multi-part, multi-disciplinary task statement worked out over a year of negotiation with NASA.
- A call to the public to submit white papers addressing the role of human spaceflight and its future was made in July 2013. The committee opened the study to public input in Oct 2013 via Twitter. Key stakeholders were also engaged.
- Representatives of past and current NASA and foreign programs, experts from academia and industry, all provided briefings to the Technical Panels and the committee

Intentions for the Report: Multiple Goals

- The NRC "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration" report was intended to provide policy guidance to Congress regarding future direction and investments in the U.S. civil space program
- Per the authorizers: The goal was to assemble a diverse group of experts, some of whom support HSF and some who do not, to investigate, evaluate and recommend to the nation a *sustainable* path forward for HSF
  - The goal of the authorizers was that the committee would also strive to answer fundamental questions- why pursue human spaceflight into the future? Should we continue?*
  - If this group of people could not come to consensus that HSF was worth continued investment – "we have a much bigger problem than near-term authorization"

Committee Membership

COMMITTEE ON HUMAN SPACEFLIGHT

JONATHAN LUNINE, Cornell University, *Co-Chair*
MITCHELL E. DANIELS, JR., Purdue University, *Co-Chair*
BERNARD F. BURKE, Massachusetts Institute of Technology (emeritus professor)
MARY LYNNE DITTMAR, Dittmar Associates Inc.
PASCALE EHRENFREUND, George Washington University
JAMES S. JACKSON, University of Michigan
FRANK G. KLOTZ,[1] Council on Foreign Relations
FRANKLIN D. MARTIN, Martin Consulting, Inc.
DAVID C. MOWERY, University of California, Berkeley (emeritus professor)
BRYAN D. O'CONNOR, Independent Aerospace Consultant
STANLEY PRESSER, University of Maryland
HELEN R. QUINN, SLAC National Accelerator Laboratory (emeritus professor)
ASIF A. SIDDIQI, Fordham University
JOHN C. SOMMERER, Johns Hopkins University (retired)
ROGER TOURANGEAU, Westat
ARIEL WALDMAN, Spacehack.org
CLIFF ZUKIN, Rutgers University

Public & Stakeholder Opinions Panel

ROGER TOURANGEAU, Westat, *Chair*
MOLLY ANDOLINA, DePaul University
JENNIFER L. HOCHSCHILD, Harvard University
JAMES S. JACKSON, University of Michigan
ROGER D. LAUNIUS, Smithsonian Institution
JON D. MILLER, University of Michigan
STANLEY PRESSER, University of Maryland
CLIFF ZUKIN, Rutgers University

Technical Panel

JOHN C. SOMMERER, Johns Hopkins University (retired), *Chair*
DOUGLAS S. STETSON, Space Science and Exploration Consulting Group, *Vice Chair*
ARNOLD D. ALDRICH, Aerospace Consultant
DOUGLAS M. ALLEN, Independent Consultant
RAYMOND E. ARVIDSON, Washington University in St. Louis
RICHARD C. ATKINSON, University of California, San Diego (professor emeritus)
ROBERT D. BRAUN, Georgia Institute of Technology
ELIZABETH R. CANTWELL, Lawrence Livermore National Laboratory
DAVID E. CROW, University of Connecticut (professor emeritus)
RAVI B. DEO, EMBR
ROBERT S. DICKMAN, RD Space LLC
DAVA J. NEWMAN, Massachusetts Institute of Technology
JOHN ROGACKI, Florida Institute for Human and Machine Cognition (Ocala)
GUILLERMO TROTTI, Trotti and Associates Inc.
LINDA A. WILLIAMS, Wyle Aerospace Group

Committee Structure for the Study

Committee on Human Spaceflight

- Technical Panel
  - Technical and engineering aspects of human space exploration
- Public and Stakeholder Opinions Panel
  - Public and stakeholder input to understand motivations, goals and possible evolution of human spaceflight

The Statement of Task I:

Consider the goals for the human spaceflight program as set forth in (a) the National Aeronautics and Space Act of 1958, (b) the National Aeronautics and Space Administration Authorization Acts of 2005, 2008, ad 2010, and (c) the National Space Policy of the United States (2010), and any existing statement of space policy issued by the president of the United States.

Solicit broadly-based, but directed, public and stakeholder input to understand better the motivations, goals, and possible evolution of human spaceflight – that is, the foundations of a rationale for a compelling and sustainable U.S. human spaceflight program – and to characterize its value to the public and other stakeholders.

Describe the expected value and value proposition of NASA's human spaceflight activities in the context of national goals – including the needs of government, industry, the economy, and the public good – and in the context of the priorities and programs of current and potential international partners in the spaceflight program.

Identify a set of high-priority enduring questions that describe the rationale for and value of human exploration in a national and international context. The questions should motivate a sustainable direction for the long-term exploration of space by humans. The enduring questions may include scientific, engineering, economic, cultural, and social science questions to be addressed by human space exploration and questions on improving the overall human condition.

The Statement of Task II:

Consider prior studies examining human space exploration, and NASA's work with international partners, to understand possible exploration pathways (including key technical pursuits and destinations) and the appropriate balance between the "technology push" and "requirements pull". Consideration should include the analysis completed by NASA's Human Exploration Framework Team, NASA's Human Spaceflight Architecture Team, and the Review of U.S. Human Spaceflight Plans (Augustine Commission), previous NRC reports, and relevant reports identified by the committee.

Examine the relationship of national goals to foundational capabilities, robotic activities, technologies, and missions authorized by the NASA Authorization Act of 2010 by assessing them with respect to the set of enduring questions.

Provide findings, rationale, prioritized recommendations, and decision rules that could enable and guide future planning for U.S. human space exploration. The recommendations will describe a high-level strategic approach to ensuring the sustainable pursuit of national goals enabled by human space exploration, answering enduring questions, and delivering value to the nation over the fiscal year (FY) period of FY2014 through FY2023, while considering the program's likely evolution in 2015-2030.

Findings – The Bottom Line:

- "If the United States is to have a human space exploration program, then it must be worthy of the considerable cost to the nation and great risk of life."
  - The Committee endorsed continuation of human space exploration
- No single rationale alone seems to justify continuing human spaceflight. Instead, it is the the sum of practical benefits and aspirational value which argue for continuation…
- …provided that the pathway principles and decision rules put forth in the report are adopted (highest priority recommendation)
- The only pathways that justify expense, continued investment and risk to crews involved are those that ultimately place humans on other worlds
- Mars is the "horizon goal", but Mars is not achievable on flat budgets or even budget rising at the rate of inflation (~2.5%)

A Strategic Approach To a Sustainable Program

- If the nation deems continuity in human spaceflight to be a desirable national objective, ***it must decide now*** on the nature of that program
- A sustainable program of human deep space exploration must have an ultimate, "horizon" goal
  - Provides a long-term focus less likely to be disrupted by failures, accidents, and vagaries of the political process and economic scene
- NASA should focus right away on the high-priority research and technology - the most challenging of these are
  - Entry, descent, and landing for Mars;
  - In-space propulsion and power; and
  - Radiation health effects and amelioration

Findings: Essential Cornerstones I

The rationales for human spaceflight are a mix of the aspirational and the pragmatic

- The primary rationale for the Apollo program was to demonstrate the technological and ideological supremacy of the United States over the Soviet Union – a conflict which is now over
- Quantification of the value of human spaceflight to the nation today, in terms of economic return or increased quality of life, is difficult.
- This does not mean that there are no benefits: W.B. Cameron wrote *"not everything that can be counted counts, and not everything that counts can be counted"*.

Findings: Essential Cornerstones II

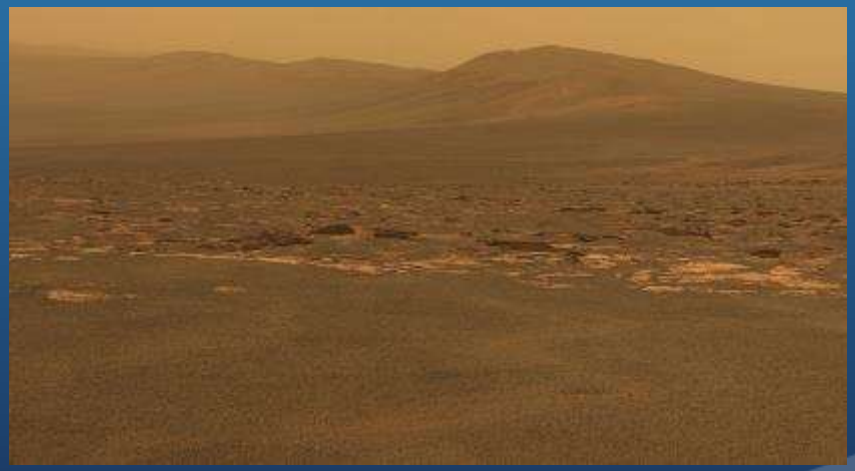
The level of public interest in space exploration is modest relative to other public policy issues

- Public opinion about space has been generally favorable over the past 50 years, but much of the public is inattentive to space exploration and spending on space exploration is not a high priority for most of the public.

Findings: Essential Cornerstones III

The horizon goal for human space exploration is Mars

- There is a small set of plausible goals for human space exploration in the foreseeable future, the most distant and difficult of which is a landing by human beings on the surface of Mars.
- All long-range space programs, by all potential partners, for human space exploration converge on this goal.



Findings: Essential Cornerstones IV

A program of human space exploration beyond Low Earth Orbit is not sustainable with a human spaceflight budget that increases only enough to keep pace with inflation.

- The current program to develop launch vehicles and spacecraft for flight beyond LEO cannot be sustained with constant buying power over time
  - it cannot provide the flight frequency required to maintain competence and safety,
  - does not possess the "stepping-stone" architecture that allows the public to see the connection between the horizon goal and near-term accomplishments, and
  - may discourage potential international partners
- The committee proposed a *pathways approach* that requires the U.S. to settle on a definite pathway to the horizon goal and adhere to certain principles and decision rules to get there

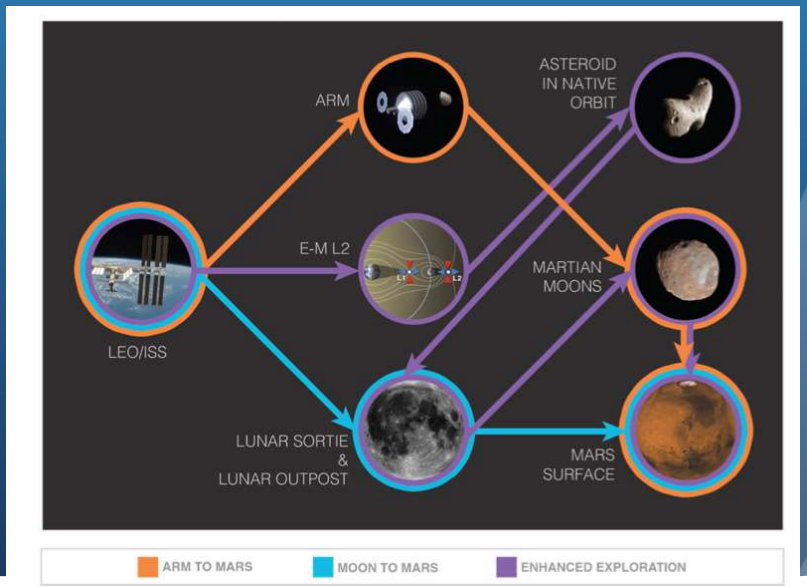
Pathways Approach: I

- Stepping stones: Between LEO and the martian surface are regions of space with stepping stone destinations reachable with foreseeable advances in the state of the art of key capabilities. These include:
  - Cislunar space, which encompasses missions to the Earth-Moon L2 point, lunar orbit, and the lunar surface (both lunar sorties with relatively short stays and lunar outposts with extended stays);
  - Near-Earth asteroids (NEAs) in their native orbits; and
  - Mars, which encompasses a Mars flyby mission as well as missions to the moons of Mars, Mars orbit, and the surface of Mars.
  - Earth-moon Lagrange points.
- Pathways approach in a nutshell:
  - A specific sequence of intermediate accomplishments and destinations normally of increasing difficulty and complexity
  - Leads to an ultimate (horizon) goal with technology feed-forward from one mission to subsequent missions
  - Destinations have cultural, geopolitical, scientific, inspirational, and/or economic value

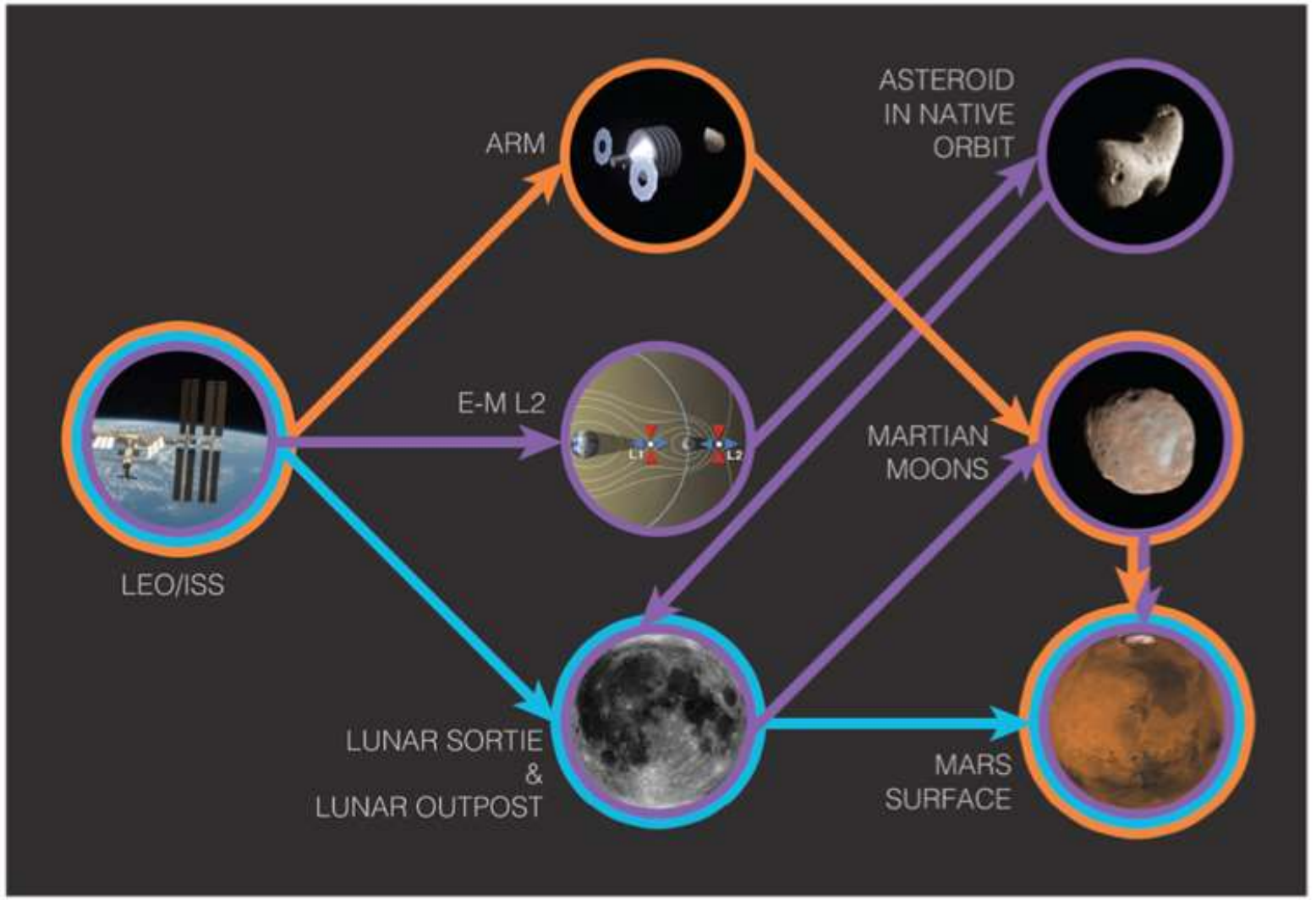
Pathways Approach: II

- NASA can sustain a human space exploration program with meaningful milestones that simultaneously reasserts U.S. leadership in space while allowing ample opportunity for substantial international collaboration when that program
  - Has elements that are built in a logical sequence, and
  - Can fund a frequency of flights sufficiently high to ensure retention of critical technical capability, proficiency of operators, and effective utilization of infrastructure.

- However, a NASA human spaceflight budget that increases with inflation does not permit a viable pathway to Mars. The program will require increasing the budget by more than the rate of inflation*.



3 Possible Pathways (not exhaustive!)



Highest Priority Recommendation: Pathway Principles I – NASA Should:

- Commit to design, maintain, and pursue the execution of an exploration pathway beyond low Earth Orbit toward a clear horizon goal that addresses the "enduring questions" for human spaceflight
  - "How far from Earth can humans go" – and
  - "What can humans discover and achieve when we get there?"
- Engage international space agencies early in design and development of the pathway on the basis of their ability and willingness to contribute
- Define steps on the pathway that foster sustainability and maintain progress on achieving the pathway's long-term goal of reaching the horizon destination
- *Seek continuously to engage new partners that can solve technical or programmatic impediments to pathway progress*

Pathway Principles II – NASA should:

- Create a risk mitigation plan to sustain the selected pathway when unforeseen technical or budgetary problems arise. *Such a plan should also include points at which decisions are made to move to a less ambitious pathway or stand down the program.*
- Establish exploration pathway characteristics that maximize the overall scientific, cultural, economic political, and inspirational benefits without sacrificing progress toward the long-term goal, these characteristics being:
  - The horizon and intermediate destinations have profound scientific, cultural, economic, inspirational, or geopolitical benefits that justify public investment;
  - The sequence of missions and destinations permits stakeholders, including taxpayers, to see progress and develop confidence in NASA being able to execute the pathway;

Pathway Principles III:

- Exploration pathway characteristics (continued):
  - The pathway is characterized by logical feed-forward of technical capabilities;
  - The pathway minimizes the use of dead-end mission elements that do not contribute to later destinations on the pathway;
  - The pathway is affordable without incurring unacceptable development risk; and
  - The pathway supports, in the context of available budget, an operational tempo that ensures retention of critical technical capability, proficiency of operators, and effective utilization of infrastructure.

Decision Rules – When problems arise….

- If the appropriated funding level and projected 5-year budget projection do not permit execution of a pathway within the established schedule, then do not start down that pathway.
- If a budget profile does not permit the chosen pathway, take an "off-ramp" (defined as "a less ambitious pathway").
- If the U.S. human spaceflight program receives an unexpected increase in budget for human spaceflight, the increase in funds should be applied to retire rapidly significant technology risks or increase operational tempo
- Give priority to those approaches that solve significant existing technological shortcomings, reduce overall program cost, allow for an acceleration of the schedule, and/or reduce developmental or operational risk.
- If there are human spaceflight program elements, infrastructure, and organizations that no longer contribute to progress along the pathway, the human spaceflight program should divest itself of them as soon as possible.

RATIONALES For Human Spaceflight: No *single* rationale justifies the value of pursuing human spaceflight.

Economic– The NASA human spaceflight program has stimulated economic activity and has advanced development of new products and technologies. It is impossible, however, to develop a reliable comparison of the returns from spaceflight versus other government R&D investments.

Security/Geopolitical--An active U.S. human spaceflight program gives the United States a stronger voice in an international code of conduct for space, enhances U.S. soft power, and supports collaborations

Education and inspiration—Space missions can serve as an inspiration for students and citizens to engage with science and engineering, although the path to becoming a scientist or engineer requires much more than the initial inspiration.

Scientific discovery--The relative benefits of robotic versus human efforts in space science are constantly shifting as a result of changes in technology, cost, and risk.

Human survival--Whether human off-Earth settlements could eventually be developed that would outlive human presence on Earth and lengthen the survival of our species is a question that can only be settled by pushing the human frontier in space.

Shared destiny and aspiration to explore--Some say it is human destiny to continue to explore space. While not all share this view, for those who do, it is an important reason to engage in human spaceflight.

Rationales (cont'd)

- Together, they argue for continued investment in, and pursuit of, human spaceflight in a manner that asserts U.S. leadership
- Caution must be exercised when making claims about the benefits of human spaceflight relative to other national investments (particularly in science)
- The historic claims were based upon a time when investment in the space program was much greater than now
  - Apollo – roughly 4.5%
  - Current investment in the entire NASA portfolio (of which HEO is roughly ½) is ~.5%
- Also, there was never a way to compare "unique" benefits of investment in R&D for one program or portfolio to that of another –
  - HSF investments yielded benefits that might have been equal to or eclipsed by other benefits – we will never be able to quantify this

Findings: International Collaborations

It is evident that U.S. near-term goals for human exploration are not aligned with those of our traditional international partners.

Most major spacefaring nations and agencies are looking toward the Moon

U.S. plans are focused on redirection of an asteroid into a retrograde lunar orbit where astronauts would conduct operations with it.

Although the United States is not expected to blindly follow the desires of other nations in shaping its own exploration program, there are a number of advantages to the United States being a more active player in lunar surface operations.

Given the rapid development of China's capabilities in space, it is in the best interests of the US to be open to future international partnerships.

- Given the scale of the endeavor of a mission to Mars, contributions by international partners would have to be of unprecedented magnitude to defray a significant portion of the cost.

Findings: Commercial Partnerships

- The report noted:
  - Completion of the commercial cargo launch development program (COTS) and transition to operations
  - The potential reduction in cost associated with new acquisition model
  - The shift of development risk to private sector for new systems
- With regard to longer term considerations, the report is more circumspect
  - The near-term objectives of commercial cargo and crew are to mitigate U.S. dependence on Russia for transport
  - Unclear whether it will reduce costs
  - Has helped stabilize and expanded the industrial base
  - Longer term –the establishment of a space-based economy with human spaceflight as a major component may be possible, but is speculative

Additional Considerations…

- The report noted that terminating the ISS earlier rather than later may open up a funding wedge for BEO exploration that could be time-critical; however it also noted that doing so would adversely impact commercial space transportation providers and hopes for a developing in-space economy in LEO
  - The Committee recommended near-term discussions with International Partners regarding implications of continuation/termination of the ISS
- Commercial approaches to and international collaboration in Beyond Earth Orbit exploration will have to greatly exceed previous levels of cost sharing (or reduction) in order to substantially impact budget profiles for various pathways

Public & Stakeholder Findings

- Summary of public opinion findings:
  - The level of public interest in space exploration is modest relative to other public policy issues.
  - Space exploration fares relatively poorly among the public compared to other spending priorities.
  - No particular rationale for space exploration appears to consistently attract support from a clear majority of the public.
  - These trends have held true over the past few decades.
- Summary of stakeholder findings:
  - With regard to human spaceflight, no single rationale garnered agreement from a majority of the respondents.
  - Support for human spaceflight goes up with involvement in work related to human space exploration
- Public & stakeholder policy environment is “permissive”, not definitive

How does the Pathways report align with NASA activities? (personal assessment))

- Committee endorsed the continuation of human spaceflight program(s) for the United States, Further, such a program should advance U.S. leadership and be worthy of the investment and inevitable lost of life.
- Committee supported increase in funding (roughly on the order of rate of inflation + 2-3%)
  - Mitch Daniels – Committee Co-Chair, to House SST Committee – "a drop in the bucket")
  - NASA – budget will require "moderate increase" in out years
- Committee endorsed international and commercial teaming on a large scale; says financial contributions must exceed any previous levels in order to offset costs of going to Mars.

Alignment (cont'd)

- Committee supports "stepping stone" approach with "feed-forward technology development"
  - NASA uses stepping stone approach; calls feed-forward "extensibility"
- Committee warns about funding levels vs. operational requirements for SLS; points out that launch cadence is not commensurate with safety.
  - NASA has called for 1X/year "necessary requirement"
- Report calls for near-term technology investment; provides a prioritized list of development
  - NASA has list and is conducting trades; many of the items overlap
  - NASA adds "SKG's" – Strategic Knowledge Gaps

Not aligned (many are policy issues….)

- China
- Committee didn't "pick" a pathway but raised questions about…
  - Asteroid Retrieval Mission (last briefed in early 2014)
  - Lunar surface operations (base)
    - International Partner interests
- Budget implications
  - Committee found increase in national investment is needed ASAP
  - Committee found that Mars was not achievable unless investment followed rate of inflation plus ~2-3%
- Divestiture of unneeded assets
  - Pointed out in other NRC reports; politically difficult

Alignment over time?

- Report calls for 'pathways approach' - goal is sustainability
  - Allows for for (a) "dropping down to another, less difficult approach" ("off-ramps") or (b) terminating program when these represent unacceptable development risk or "break the budget"
  - Together with other recommendations, this is Intended to ensure ability to continue development in the face of programmatic or budgetary obstacles
  - Pathways approach intended to provide guidance for NASA
    - "Evolvable Mars Campaign" incorporates some of the principles (feed-forward, partnering, minimizing dead-ends, tech investment)
- NASA's approach is 'capability-based' …goal is sustainability
  - Budgetary constraints
  - Policy environment
  - Time (a program on the order of **multiple** decades, rather than a decade or two…)

Some Final Thoughts

- The aggregate benefits and value to society of both the practical benefits and aspirational goals related to human space exploration justifies our national investment and continuation of the program
- Given the investment, the need for partnerships, and the goal of establishing a pathway and developing/executing along it, NASA must evolve
  - Will require NASA to divest what it doesn't need or can acquire through other means at lower cost, or can partner for
- NASA must harvest wisely
  - Turn over every rock – industry, tech development, international collaboration
  - Must challenge assumptions and sacred cows, but don't throw the baby out with the bathwater – this is a tough balancing act!
  - Much greater complexity of the endeavor than in the past (even greater than ISS)
- Sustainability is the key – we are "playing the long game"