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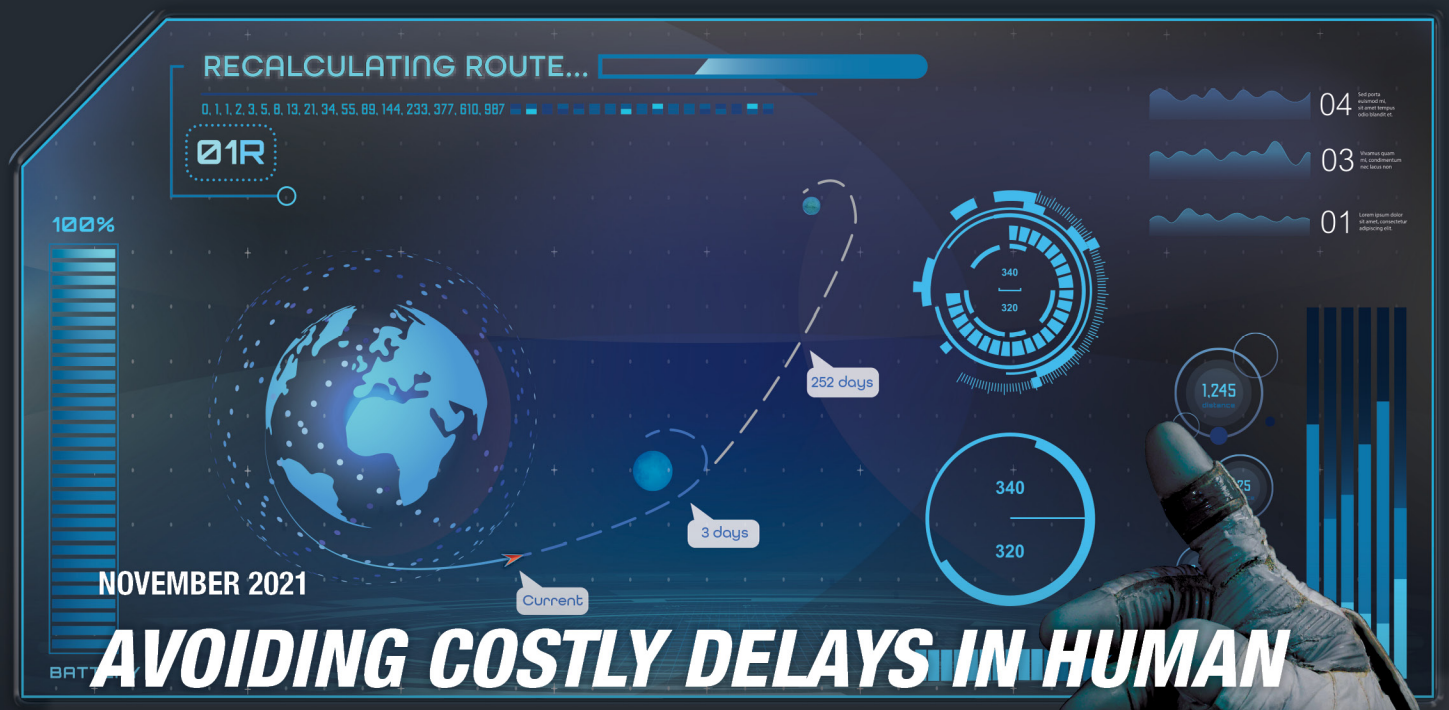

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AVOIDING COSTLY DELAYS IN HUMAN SPACE EXPLORATION: HISTORICAL PERSPECTIVES ON NASA PROGRAMS

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Summary

This paper examines the historical impact of major changes in the human space exploration program objectives at NASA and draws lessons from those experiences that may be of value to current and future administrations. We trace the program history of NASA's human exploration programs through various presidential administrations, starting with the George H. W. Bush administration and moving through to the present day. Along the way we identify and document the sources of program changes and make observations about what went well and what did not go well, exposing the true cost and other consequences of disruptive change. We also highlight the importance of making necessary changes when something is not right. Presidential administration changes and annual budget deliberations are times of great opportunity but also of great risk, and decisions need to be made with eyes wide open, not only to the potential benefits but also to the unintended negative consequences some changes may have. These factors need to be considered by a new administration and Congress when they are faced with decisions to change things or "stay the course." The lessons may apply well beyond NASA.

Introduction

Although significant changes in direction can occur at any time in government, the start of a new presidential administration is often a time of significant change. Changes in leadership, priorities, policies, and direction are likely, as each president wants to make a mark and leave a legacy. Shortcomings of previous approaches are likely to be acknowledged during these transitions as well. Historically, setting the direction for human spaceflight has been an area of significant interest, with many stakeholders and billions of dollars invested every year. It is also a very long-term endeavor, which has and will continue to span multiple administrations and Congresses. In the past three decades, every president has attempted to shape or reshape the human exploration programs, with huge impacts to actual progress.

Congress, of course, has the last word on funding whatever a president proposes. Congressional action (or inaction) thus adds a layer of complexity and uncertainty that may dampen, amplify, or completely change program direction. Sometimes NASA and presidential administrations seek to anticipate or counterbalance that congressional intervention. These various kinds of changes can have repercussions through the bureaucracy and may unintentionally extend the cost and timeline for the United States to achieve space exploration milestones.

This paper examines and traces the program history of NASA's human exploration programs through various presidential administrations, starting with the George H. W. Bush administration and moving through to the present day. The various twists and turns, and especially the goal changes and resulting budget and program design ramifications, are described. The impact of changing the overall objectives of U.S. human space exploration (from Mars to the moon, to technology, back to the moon, etc.), as well as the underlying complexities of design changes and even contract cancellations or modifications, will be explored.

Learning from History

> ***"Those that fail to learn from history, are doomed to repeat it."***
>
> —Winston Churchill

The design of current exploration systems is the result of a fascinating combination of technical capabilities, program gyrations, and political tradeoffs. A review of the historical record reveals some common themes and allows us to make observations leading to a sharper understanding of the true cost and other consequences of disruptive change. These factors need to be considered by a new administration and by Congress when they are faced with decisions to change things or "stay the course."

Each president, except perhaps Bill Clinton, made a bold announcement of the vision for human exploration—a more long-range, strategic, and global vision—that would typically require subsequent administrations to continue executing. George H. W. Bush and George W. Bush both tried to set a long-term vision for human spaceflight beyond low Earth orbit (LEO), but their efforts did not continue much past the end of their administrations. Barack Obama sought to bypass the moon, opting for technology to enable exploration leading to asteroid and Mars missions. Donald Trump returned to a "moon first" approach with Artemis. Joe Biden has supported Artemis for now.

Observation 1: Competing stakeholder interests can disrupt the nation's ability to make progress in human exploration beyond LEO.

Since the Apollo Program ended, human travel to destinations beyond LEO has generally lacked a consistent guiding vision adopted by all stakeholders (in the executive branch, Congress, industry, and the public). Presidents want to leave a legacy, put their stamp on the future, and contribute to future generations. Members of Congress also desire the general good, but especially want to bring benefits to their states and local districts. Most politicians seek reelection. Old and emerging space companies want stable, long-term programs that generate profits, and some new space entrepreneurs are pursuing their own independent visions for the future. (For example, Elon Musk of SpaceX is pursuing his grand vision of sending humankind to Mars.) The broadest group of stakeholders is the taxpayers, many of whom want to see government funds used wisely to make substantive progress toward goals that excite them and provide long-term scientific or quality-of-life benefits. These stakeholders have differing motivations and timelines driving their priorities, and it is extraordinarily difficult to get them all pulling in the same direction. When one or more of these groups disagree or move on a different path, progress slows or halts altogether. NASA has found it necessary to balance often conflicting desires of multiple stakeholders to obtain the resources necessary to execute its programs, and the progress has been slow and inconsistent as destinations and methods to reach them have changed over the years. Table 1 shows the changes to human spaceflight plans across administrations since the George H. W. Bush administration. The most ambitious destination goals are shown in bold font.

Table 1: Human Spaceflight Changes Across Administrations

President	Presidential Proposals for Human Exploration	Congressional Response	End Result
George H. W. Bush Administration (1989–1993) Space Exploration Initiative (SEI)	30+ year Apollo-style plan, Space Station Freedom, permanent lunar presence, humans on Mars **LEO/Moon/Mars**	Space and Earth science, "go-as-you-pay" exploration **LEO/Moon/Mars**	SEI canceled.; space shuttle and down-scoped Space Station Freedom due to budget constraints. **LEO Only**
Bill Clinton Administration (1993–2001)	Space shuttle and redesign of the Space Station Freedom (now International Space Station) to reduce costs. **LEO Only**	Almost canceled Space Station Freedom. **LEO Only**	Assured Crew Return Vehicle (ACRV) Program for ISS emergency return; Reusable Launch Vehicle (RLV) program and X-33 VentureStar. **LEO Only**
George W. Bush Administration (2001–2009) Vision for Space Exploration (VSE)	Retire the space shuttle by 2010; develop new and separate space transportation systems for crew and cargo; return to the moon by 2020 (constellation); reach Mars someday. **Moon/Mars**	Congress codified VSE in 2005; initiated Constellation Program. **Moon/Mars**	Constellation reaches preliminary design review; NASA tests Ares I-X vehicle and Orion Pad Abort Test; work begins on J-2X upper stage engine; RLV programs canceled (X-33, ACRV/X-37, Orbital Space Plane). **Moon/Mars**
Barack Obama Administration (2009–2017)	Canceled the Constellation Program and replaced it with six new technology lines to enable eventual human exploration; initiated Commercial Crew Program (CCP) for ISS transportation. **Asteroid**	Congress objected, directing NASA to create a new space launch system (SLS) and continue the Orion and Ground Systems Development and Operations (GSDO) projects; reduced funding for CCP. **Cislunar Space**	Authorization Acts passed (2010, 2016); unanimous approval to use ISS through 2024 and to develop propulsion technologies and strategic framework for humans-to-Mars missions; Obama's six enabling technology lines were not funded; asteroid redirect as a destination funded. **Asteroid/Mars**
Donald Trump Administration (2017–2021)	Focused on opportunities to accelerate major progress milestones (for SLS and CCP); started the Artemis Program with 2024 moon landing goal "by any means necessary." **Moon/Mars**	Congress continued to fund the SLS, Orion, and Exploration Ground Systems (was GSDO) at rates higher than requested; funding for Gateway and HLS fell short of request. **Moon/Mars**	Transition Authorization Act of 2017—continued ISS, SLS, Orion, GSDO, and CCP; Gateway and HLS programs initiated. **Moon/Mars**
Joe Biden Administration (2021-)	First budget proposes 7% increase for NASA; includes continuation of Artemis and retains 2024 landing goal. **Moon/Mars**	As of this writing, Congress appears to be leaning toward increased NASA funding, but that does not ensure a 2024 landing. **Moon/Mars**	TBD

Note: The most ambitious destination goals are shown in bold font.

Observation 2: Disruptions are costly. Frequent changes to the goals for U.S. human exploration waste resources and impede progress.

During several presidential transitions, various stakeholders interacted, resulting in disruptive change at NASA. Understanding the true cost of changing the program goals of U.S. space exploration is key in determining whether the change is worth the disruption. How much do changes impact program costs? The Department of Defense (DOD) has taken pains to track this for its programs, which are similar in size and complexity to many NASA programs. In its 2013 report on the Performance of the Defense Acquisition System,[1] DOD noted that for the 176 Major Defense Acquisition Program (MDAP) contracts executed between 1992 and 2011, 69 percent of all cost growth was due to changes in work content. The effect was most pronounced for space programs, for which each 1 percent change in work content resulted in a 1.13 percent increase in cost. A similar phenomenon surely takes place when changes are made to NASA programs.

Changes in direction and goals can also result in outright program cancellations. Over the past 30 years, based on an assortment of agency documentation, NASA has spent at least $19 billion on canceled development programs. Of that total, $7 billion for human spaceflight beyond LEO was lost from cancellations or mothballed facilities stemming from changes in administration or congressional direction. The sunk costs due to canceled programs might have been even higher if NASA had not utilized some of the hardware from those canceled programs for follow-on efforts (although the repurposing of existing hardware sometimes constrained options). Had there been a long-range blueprint for human exploration with the necessary funding, program redirection and cancellation costs might have been avoided and progress toward achieving the vision maintained. From a mission accomplishment perspective, even worse than the approximately $7 billion lost in canceled programs has been the time squandered.

Observation 3: Sometimes changes in vision or program direction are necessary.

Of course, change can be beneficial and even necessary under certain circumstances. We may discover that a particular technological approach for space exploration just will not work, or that there are new technical difficulties that have arisen as we have learned more about the challenge. In some circumstances, agency managers may intentionally include program redundancy in pursuit of industry competition, and later downselect to the best solution. New geopolitical realities (such as emerging competition with near peers) can change the nature and timeline of U.S. goals and the composition of international partnerships. New business models may arise while others become impractical or obsolete. Technology may advance in a way that makes it advantageous to move in a completely different direction. Changes in the mix and motivations of stakeholders may require adjustments. The key is to measure the benefits of any change against the disruptions that it will inevitably cause. A review of the history of human space exploration highlights some examples of beneficial changes that have been made.

Historical Review by Presidential Administration

Figure 1 shows the human exploration timeline across administrations, starting in 1985, and the programmatic changes that occurred across more than three decades.

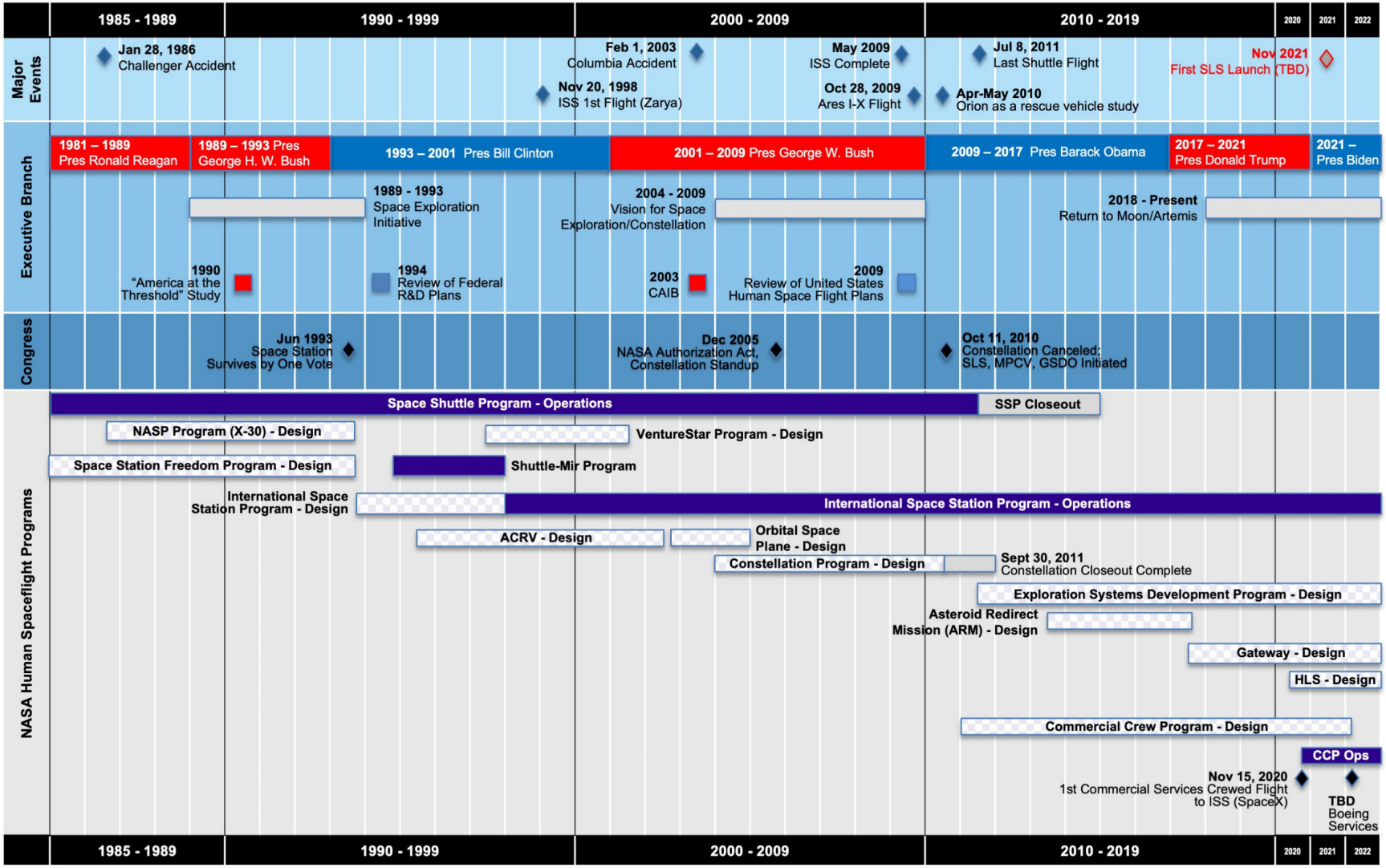

Figure 1: Historical view of human spaceflight programs.

George H. W. Bush Administration

Starting with the first Bush administration (1989 to 1993), planning for human exploration beyond LEO built upon President Ronald Reagan's *Pioneering the Space Frontier*[2] vision of initial operation of a permanent space station and dramatically lower-cost transport vehicles to and from LEO for cargo and passengers. President Bush commissioned a 90-day NASA study for the Space Exploration Initiative (SEI) in 1989[3] to further mature plans and understand the associated costs. The result was a 30+ year Apollo-style plan, including Space Station Freedom, permanent lunar presence, and humans on Mars with a price tag of $500 billion over a 20- to 30-year time frame. Congressional **stakeholders were not aligned**, and resistance from budget hawks led to the creation of the Augustine Committee,[4] established in 1990 by Vice President Dan Quayle, who chaired the National Space Council. The committee recommended NASA focus on space science and Earth science, and transition human exploration to a "go-as-you-pay" endeavor. In 1992, NASA shifted to a "faster, better, cheaper" strategy under the leadership of NASA Administrator Dan Goldin, and the human spaceflight focus was narrowed to LEO programs such as the space shuttle and a scaled-down version of Space Station Freedom. Although Mars remained the ultimate objective, NASA adjusted its mission portfolio and stretched the timeline to stay within budget limits. **Misaligned stakeholders resulted in very slow progress.**

Bill Clinton Administration

During the Clinton administration (1993 to 2001), NASA's vision for LEO initially "stayed the course" set late in the George H. W. Bush administration but added broader collaboration with Russia in the wake of the breakup of the Soviet Union. Space Station Freedom development and space shuttle operations moved slowly forward to success but at a cost that left little for human exploration beyond LEO. SEI did not survive beyond the George H. W. Bush administration, and human exploration never advanced beyond the concept phase. While basic space technology efforts continued, there was no longer a unifying objective for human missions beyond LEO. Mars was dropped as an official destination. Between $115 million and $130 million had been spent on SEI efforts during the previous administration, with little value applied to future efforts.[5] Human spaceflight activities focused on LEO with the continuing operation of the space shuttle and yet another redesign of Space Station Freedom to reduce costs. Freedom had already undergone several scope reductions from 1984 through 1993. Each design iteration resulted in **disruptive change**, reducing Freedom's capability, size, and complexity. Although these iterations were intended to reduce the overall cost and accommodate the program within anticipated budgets, the opposite occurred. **Cost overruns increased with each design iteration**, and the resulting space station configuration had a diminished capacity to perform meaningful science.

By June 1993, Congress had lost confidence in NASA's ability to control costs and proposed an amendment to remove space station funding from NASA appropriations. The amendment failed by one vote in the House of Representatives, and Space Station Freedom avoided cancellation. Freedom was redesigned *again*, this time to include partnership with Russia and renamed the International Space Station (ISS). The Clinton administration did achieve completion of the ISS design and the beginning of assembly in space, with the first crew on board in the final year of the administration (2000). These space station redesigns affected NASA's ability to fund human exploration initiatives. NASA spent $11.2 billion (in 1995 dollars) designing and developing earlier versions of the space station during fiscal years 1985 through 1993.[6] In 1993, the Government Accountability Office (GAO) estimated that ISS development

would consume 22 percent of NASA's annual budgets through 1998 and 39 percent of NASA's annual budgets from 1998 through 2000.[7] The space shuttle continued to fly safely, but human exploration initiatives were put on the backburner.

A similar story played out with launch vehicles. In 1994, NASA initiated the Reusable Launch Vehicle (RLV) Program to develop and demonstrate technologies to reduce the cost of access to space and make U.S. aerospace manufacturers more competitive in the global market. The X-33 VentureStar Program was started in 1996 but, due to cost overruns, was canceled in early 2001 after a $1.5 billion investment. **NASA's experience with both ISS and RLV support the observation that disruptive change is costly.**

George W. Bush Administration

The George W. Bush administration (2001 to 2009) left Clinton administration policies unchanged until the STS-107 Columbia accident on February 1, 2003. The Columbia Accident Investigation Board (CAIB) study influenced NASA's long-term future plans by recommending the retirement of the shuttle as soon as possible and by calling for a clearer picture of how a new space transportation system would fit into the nation's overall plans for space.[8] As a result, on January 14, 2004, President Bush announced the Vision for Space Exploration[9] (VSE), which directed NASA to retire the space shuttle upon completion of ISS, develop a new space transportation system that separated crew from cargo launches, return to the moon by 2020, and eventually reach Mars. President Bush's announcement **was supported by Congress** and was later codified in the NASA Authorization Act of 2005. NASA now had a vision and authority to restart human exploration and initiated the Constellation Program in 2005. A clearly defined vision for a real exploration program was established for first time since Apollo.

The Constellation Program focused on developing two launch vehicles, Ares I Crew Vehicle and the Ares V Heavy-Lift, with the Orion crew capsule and the ground systems common to both. An initial operational capability (IOC) for ISS transportation was targeted for 2012, with 2020 planned for the human lunar mission. During the last three years of the administration, the Constellation Program progressed toward the preliminary design review phase, with preparations to launch the Ares I-X test vehicle and demonstrate the Orion Pad Abort-1 test and J2X upper stage engine.

Despite top-level alignment between the administration and Congress, **costly disruptive change was still happening at lower levels.** For example, astronaut safety and return from the ISS had always been important to NASA's human spaceflight plans but had endured many disruptions, ultimately costing the taxpayers billions of dollars. Congress canceled the X-38/Assured Crew Return Vehicle (ACRV) in 2002 (after spending approximately $485 million through 2001[10]) because of its limited mission capability (crew return only). Later, Congress directed NASA to pursue the Crew Transfer Vehicle (CTV). The CTV, later called the Orbital Space Plane (OSP), had an expanded mission to serve as both crew transport to the ISS and as the crew return vehicle. In 2003, three contracts were awarded for a total of $135 million in preparation for an eventual selection of one provider. Once again, Congress felt the OSP mission was too narrow for its anticipated $5 billion price tag, canceling the OSP Program in 2004. NASA then restructured its programs to support administration plans for moon and Mars exploration, changing OSP to the Crew Exploration Vehicle, now called Orion. The crew transportation system destination whipsawed due to changing priorities from both Congress and the executive branch, resulting in sunk costs of over $620 million.

Barack Obama Administration

After reviewing the NASA portfolio, the Obama administration (2009 to 2017) initiated the Augustine Commission in 2009 and published a report that found the Constellation Program unsustainable without significant additional resources. Constellation had progressed through a good portion of the design and development lifecycle, but it was facing extremely challenging budget conditions and experiencing schedule delays. The Ares I-X and Orion Pad Abort 1 test flights were successfully flown during the first 18 months of the Obama administration, but a decision then had to be made whether to provide the funding needed to continue. The FY11 President's Budget Request (PBR) canceled the Constellation Program and replaced it with six new enabling technology programs, along with the creation of the Commercial Crew Program (CCP) for ISS crew transportation as a service.

President Obama's proposed program changes generated major pushback from Congress, with members sending numerous letters to the NASA administrator saying that NASA was canceling portions of Constellation in violation of the FY10 appropriations act. The congressional resistance was bipartisan. Republican and Democratic members teamed to preserve the Constellation Program funding in their districts (e.g., Alabama Republican Senator Richard Shelby supporting the Space Launch System and Florida Democratic Senator Bill Nelson supporting Exploration Ground Systems [EGS] at the Kennedy Space Center). In April 2010, the Obama administration tried to compromise, making an announcement to continue the Orion Program as an ISS emergency return vehicle with a plan to complete the design of a new heavy-lift launch vehicle by 2015. The compromise did not appease congressional concerns. Congress instead pushed through legislation directing NASA to continue the Orion "multi-purpose crew vehicle," originally optimized for LEO ISS transportation, for crewed cislunar missions. Congress also directed NASA to immediately pursue designing a heavy lift launch vehicle now known as the Space Launch System (SLS). The legislation further specified use of the existing Constellation Program contracts for both. Constellation's Ares I launch vehicle was canceled. The legislation did fund CCP development for ISS crew transportation but at a reduced rate and on a longer schedule than requested by Obama, extending U.S. dependency on Russian Soyuz flights for access to the ISS after retirement of the shuttle in 2011. In the end, the six enabling technology programs originally proposed by President Obama were never funded. **Without stakeholder alignment**, NASA designers lacked a mission design goal until the Obama administration established a mission to retrieve a boulder from an asteroid, relocate it to cislunar space, and then visit it with a crew by 2025. A human mission to Mars by the mid-2030s was also included. Other lunar missions were no longer part of the strategy.

The **stakeholder landscape also changed** dramatically during the Obama administration as new space companies, or "New Space" as some have called them, such as SpaceX, Blue Origin, and Virgin Galactic began to come into their own. Led by a new group of space entrepreneurs, they have very **different motivations** than the federal government: creating a new businesses, bearing most of the risks, and benefiting from the rewards (profit). The New Space entrepreneurs are demonstrating the motivation and capability to accomplish their independent visions. The Obama administration continued the trend, shifting space policy toward commercial services versus the traditional relationship between the federal government and established "Old Space" prime contractors. Tension grew between New Space and Old Space as they competed for limited NASA resources. The **increasing misalignment** caused inefficiencies as programs started and stopped or received inadequate funding.

NASA's dual launch vehicle architecture also experienced **disruptive change** and significant losses due to Constellation's cancellation. The cancellation of Ares I and Ares V and the shift toward the Space Launch System combined for a loss of $4.85 billion over a five-year period. Ares I-X, the prototype for the Ares I launch vehicle designed to launch Orion to the ISS, was originally put into the Constellation test program as a knowledge capture effort to create new computer models for the shuttle booster that would fly as the first stage of an inline rocket. The Ares I-X launch occurred, for a total cost of $445 million,[11] but the benefit of the test was never realized since it could not be applied to the Ares I launch vehicle design. Similarly, the J2X upper stage engine for both the Ares I and Ares V launch vehicles and the associated A-3 test stand at Stennis Space Center were both canceled and mothballed just short of engine testing. The total cost for J2X development and A-3 test stand construction at project cancellation was $1.7 billion and $349 million, respectively. Finally, the Ares V launch vehicle and RS-68 core stage engine development were also canceled when Congress directed NASA to build the Space Launch System. The RS-68 partnership with the Air Force intended to develop low-cost common core stage engines and benefit from lower recurring and non-recurring costs for both agencies was never realized. The sunk cost associated with the Ares V and RS-68 designs was approximately $50 million. Combining the X-33 and Ares I/V launch vehicle costs incurred during development, a total of $6.35 billion was lost.

The changes made by the Obama administration and Congress yielded positive and negative impacts. On the positive side, development was not sidelined, and the architecture adjustments eliminated technical and affordability weaknesses in the Constellation Program. The cancellation of the Ares I launch vehicle simplified development efforts somewhat, moving to one launch vehicle instead of two, reducing future funding outlays while also eliminating the need to address a major technical issue (thrust oscillation). However, the Ares I cancellation also mothballed systems that had been close to completion. The schedule to achieve initial operating capability was lengthened since NASA had to divert effort toward the design of the heavy lift launch vehicle. Restricted by Congress to using the existing Constellation Program contracts, NASA was **forced to modify designs within the contract constraints, which resulted in suboptimal capabilities** to support the new mission objectives/destinations.

Examples of Positive Change: Commercial Cargo and Crew, and Updated National Space Policy

During the George W. Bush administration, NASA initiated Commercial Resupply Services, signing contracts in 2008 with SpaceX and Orbital Sciences to deliver cargo to the ISS as a service.

The Commercial Cargo Program and the Obama administration's Commercial Crew Program were both examples of **positive changes** for NASA's mission. They were necessary to eliminate U.S. reliance on Russian crew and cargo transportation services for the ISS following the shuttle retirement and for reducing the costs of crewed LEO spaceflight. In 2020, American astronauts again launched into space from American soil after a nine-year hiatus. The Trump administration's iteration of the National Space Policy was also positive, promoting a robust commercial space industry, returning Americans to the Moon and preparing for Mars, leading in exploration, and defending the United States and allied interests in space.[12] The intent of this policy change was to further enable and facilitate the growth of the emerging commercial space sector through public-private partnerships, generating new markets and fostering innovation-driven entrepreneurship.

Donald Trump Administration

When the Trump administration (2017 to 2021) took office, the designs and hardware production for SLS, Orion, and EGS initiated under the Obama administration had matured significantly. Although still years away from integrated flight testing, Orion had successfully flown an orbital un-crewed test flight in 2014. SLS and Orion flight hardware for un-crewed and crewed flight testing was being manufactured and assembled. EGS infrastructure, such as the mobile launch platform and vehicle assembly building platforms, were nearly complete. Commercial crew partners were also nearing test flights. **Avoiding disruptive changes** to the programs implemented during the Obama years, the Trump administration instead focused on opportunities to accelerate major progress milestones. Even before a NASA administrator was nominated, the White House directed NASA to investigate the possibility of flying crew on the first integrated SLS/Orion test flight around the moon, known then as Exploration Mission 1 (EM-1). The goal was for this to occur well before the next presidential election cycle. The resulting cost estimates to upgrade the existing EM-1 hardware to support crew, as well as additional suborbital test flights to reduce risks and unknowns regarding Orion's heatshield, proved impractical.

In December 2017, the Trump administration officially ended the Asteroid Redirect Mission (ARM) and directed NASA to return to the moon.[13] Trump reinstituted the National Space Council (NSpC), which had not existed since the George H.

The Long History of the Orion Spacecraft

The history of the Orion spacecraft is an instructive example about the impacts that **disruptive program changes** can have; top-down directed changes to programs well into their development phase can result in compromised technical capabilities and nonoptimized system-level designs. Since its inception, the Orion spacecraft has been aimed at different initial destinations as directed either by Congress or the administration. During the Constellation Program, Orion design work focused on a "Phase 1" version, optimized for crew transport to and from the International Space Station in LEO, to be followed years later by a "Phase 2" version for the moon with greater capabilities. Change initiated by the Obama administration, and modified by Congress, resulted in Orion being redirected toward cislunar space as the first destination, to visit a boulder retrieved from an asteroid. Then under the Trump administration, it was redirected again to immediately support lunar missions. Based on the authors' experiences, NASA elected to continue certain Phase 1 Orion design capabilities for the cislunar and lunar destinations without the Phase 2 enhancements. As a result, Orion's service module propellant capacity, while adequate for its original LEO mission, remained undersized for entering and departing low lunar orbit (unlike the Apollo command and service module).

Partly to accommodate Orion's limitations, NASA's plan for a lunar return was altered to include a lunar Gateway—a mini space station—in a near-rectilinear halo orbit (NRHO) that is reachable by Orion. The Gateway offers some advantages for long-term sustainability of human lunar presence, enabling extended mission durations and providing a staging and refueling location for elements of the architecture to be reused (such as ascent and transfer vehicles). Other mission concepts avoid using the Gateway for bringing crew to the surface, accommodating Orion's limitation by requiring greater performance from the lander system.

Although not entirely quantifiable, each Orion destination redirection caused changes that resulted in additional cost, schedule, and/or performance impacts. The Orion program, started in 2004, has yet to become operational. Orion's first un-crewed flight with the SLS will be the Artemis 1 mission, likely no sooner than early 2022, and its first crewed test flight is now scheduled for 2024—two decades after program start.

W. Bush administration, to establish an integrated space policy across multiple government agencies and to bring in industry and academic perspectives. Through the NSpC, NASA was challenged to accelerate the human exploration development schedules by approximately four years, creating the Artemis program to land the first woman and next man near the lunar south pole by 2024. The Trump administration attempted to balance the obvious political motivation for the first landing's schedule by proposing not just short flag-planting, footprint-stomping sorties; rather, the Artemis Program also included specific plans for building a sustained lunar presence on subsequent missions. This included affordability considerations, such as reusable lander components and refueling as well as building infrastructure on the lunar surface. The administration eventually defined the ultimate objective as Mars, to be enabled by what would be learned from repeated long stays on the moon. NASA later published the Artemis Plan documenting how the agency would implement the administration's direction.

In a public NSpC meeting, Vice President Mike Pence made it clear this goal was to be achieved "…by any means necessary."[14] This direction for accelerating achievements that would be publicly compelling had the effect of putting additional pressure on the exploration programs to achieve their planned schedules for the first three flights. It also pushed NASA to implement innovative and accelerated acquisition strategies for the Gateway and Human Landing System (HLS) programs by using existing technology development acquisition mechanisms to make early progress with techniques proven by the CCP. NASA invested significant resources and efforts in communicating and selling the 2024 Artemis objective, with special emphasis on landing a woman on the moon for the first time. In addition to the positive public reaction, this generated enthusiasm and momentum within NASA. This combination of a compelling goal, with buy-in from Congress, industry (including New Space players), and even international partners through the Artemis Accords **created strong alignment** across the stakeholder community. Emerging competition from China probably contributed as well.

By the end of the Trump administration, NASA had in place contracts for all early elements of the Gateway, as well as contracts with three competing commercial partners for HLS. Broad alignment around key goals only went so far, however. Congress, in the FY21 appropriations for NASA, provided only part of the requested funding for HLS development, which inhibited NASA's ability to maintain multiple commercial partners through the development phase.

Joe Biden Administration

Although still in its first year, the Biden administration has **endorsed the continuation** of the Artemis program, and the new NASA administrator even endorsed the 2024 timeline. The Biden administration proposed significant budget increases for NASA and has started to set some space priorities (notably an increased emphasis on climate science). Time will tell whether NASA can effectively balance the benefits of program continuation while identifying and pursuing necessary change.

Figure 2: Artemis Program Hardware.

Principles and Recommendations

Now that we have reviewed more than 30 years of presidential administrations, congressional actions, and NASA human exploration programs, what general principles can be identified to benefit current and future decisionmakers?

- First, it is apparent that disruptive change usually leads to suboptimal results. Program costs increase, schedules stretch, cancellations waste funds that could be used more efficiently, and design compromises on the follow-on programs limit performance or make goals harder to achieve.*
- Second, it is vital to understand the full impacts and especially the possible unintended consequences of proposed changes before implementing them. It is generally wise to take time to ponder and study programs thoroughly before making changes.
- Third, identify modifications that do need to be made, and do not be afraid to take action to correct flawed programs or adjust to external changes (e.g., increased commercial space capabilities, changing stakeholder motivations, etc.).

Here are some recommendations we feel are critical for current and future leaders in Congress, the Executive Branch, and Industry to consider.

- **Implement Strategic Planning**
  - The United States human space exploration program would benefit from a long-term strategic vision agreed to by stakeholders in both major political parties, by the executive branch, and by the Congress. Building and maintaining a coalition of interested stakeholders is essential to making progress toward achieving such a vision.
  - Foresighting, "future back," and other strategic planning exercises that examine provocative future scenarios allow leaders to identify things that can be done to improve readiness and flexibility. Future scenarios that could be considered include a Chinese or

* It should be noted that we cannot always predict what might have happened to a particular program without the disruptive change. The result could have been better or worse than the alternative that was selected.

Russian moon base; a Chinese crewed Mars landing; confirmed evidence of extraterrestrial life, economically feasible resource extraction on the Moon, and planetary defense against an impact threat to Earth.

- **Maintain Momentum**
  - Momentum matters. If significant progress has been made toward a worthy goal, try to keep things going. Send early signals of support. The lack of a signal, even for a project with strong support, will cause uncertainty to grow and will dampen progress. It is essential to keep the workforce, government stakeholders, industry, and the public engaged.
  - Even if the executive/legislative process or other factors slow things down, push forward as much as possible, even in an underfunded environment. Prioritize key elements and technologies—ask which elements are most adaptable for the future, and ask which elements are no longer useful and should be cut. Anticipate budget scarcity but have plans ready for a windfall (expect the worst but plan for the best).
- **Maintain Flexibility**
  - Consider opportunities for change if some architecture elements are still flexible (like the Lunar Gateway or even the SLS). Keep options open and resist the urge to lock down the architecture before contractors have a chance to propose innovative ways forward.
  - Foster flexibility in systems and architectures so that future administrations or legislatures can change mission priorities (e.g., the moon vs. Mars) without causing complete redesigns of launch vehicles and spacecraft or needing costly new elements.
  - Work with all stakeholders to implement acquisition flexibility and minimize direct contracting actions in legislation, encourage multiple contracting pathways and multi-year funding where appropriate, etc.
  - Reevaluate architectures and other elements when acquisition decisions are made that might change the "big picture." For example, the recent selection of the SpaceX Starship system for the HLS could lead to consideration of whether the SLS is still needed if a Starship heavy launch system is available.
- **Establish Vision and Branding**
  - Set a common vision. After understanding the identities and motivations of the stakeholders, it is the role of the federal government to set an overall ecosystem vision that defines each stakeholder's role and allows place for yet unknown players. The government should also find the most common ground across all stakeholders, allowing these forces to work together to reinforce positive outcomes. Additionally, it should foster environments that enable innovation and set standards (e.g., for public safety) but do not define detailed requirements.
  - Cautious linking of a program to strongly positive goals and concepts like "first woman on the moon" can be effective in preserving a vision from one administration to the next. It is quite difficult to argue against putting a woman on the moon, especially after the concept has generated broad public support. But these rhetorical approaches should be

used with caution as they can easily tie the agency's hands and constrain choices if the situation changes.

- Harness and continue to fuel the public's excitement, engagement, and imagination related to space exploration, which is at this point in history already running high. There may be no factor more important than this to achieve long-term (multi-administration, multi-congress) support for a national human space exploration goal and the programs needed to reach it. Media campaigns are part of any solution (public relations experts, explanatory animations, interviews, etc.) to fix something positively in the public eye. So are results.

Conclusion

After considering the last 30 years of relevant NASA programs, it is clear that development of a human exploration endeavor is a multi-decade initiative that requires a sustained effort with a significant level of agreement between the executive and legislative branches to ensure progress. The results come when disruptive change by each administration or by Congress is limited. A unified vision embraced by all stakeholders (executive branch, Congress, emerging space companies, and the public) offers the greatest probability for success.

Why does this matter? Because NASA has been entrusted not only with significant resources, but also with a significant portion of the public's hopes and dreams for the future. Money spent wisely to achieve a unified vision will be rewarded with continued good will, increasing public support, and, most importantly, steady progress toward expanding the frontier of human space exploration and knowledge.

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