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The political sustainability of space exploration

David A. Broniatowski*, Annalisa L. Weigel

Department of Aeronautics and Astronautics, Engineering Systems Division, Three Cambridge Center, NE20-343, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

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Abstract

The swiftly changing policy environment introduces significant uncertainty into the design of technical systems that rely on public resources. Politics necessarily impacts technical design as requirements change to suit different needs. Simple game-theoretic models may be used to provide insights into resource allocation dynamics between the National Aeronautics and Space Administration (NASA) and the US Congress. This paper utilizes game theory, supplemented by Brams' Theory of Moves, to model the process by which stakeholders within NASA and the US Congress may arrive at an affordable and politically sustainable funding level on a yearly basis. In doing so, this paper advances a game-theoretic definition of political sustainability.

1. Introduction

As a member agency of the American Executive Branch, the National Aeronautics and Space Administration (NASA) is subject to political forces. Furthermore, NASA's systems, along with aerospace systems in general, are becoming increasingly complex, with longer design lifecycles, especially when contrasted with the American presidential term of 4 years, and the Congressional impetus to demonstrate concrete results and economic returns to electoral districts prior to the biennial election cycle. A system designed under these circumstances must be able to deliver value under a constantly shifting political environment if it is to survive. These systems must therefore have an architecture that allows for political sustainability. Once the system has been defined, political sustainability becomes an issue of maintaining the support that currently exists and potentially building the base for future support. In the case of NASA's systems, this support often takes a budgetary form. Budgetary political sustainability is aimed at maintaining a program's support among the public, within Congress, and, more generally, among all invested stakeholders. In particular, budgetary political sustainability has proven to be a driver for the Vision for Space Exploration, which instructs NASA to "Implement a sustained and affordable" space exploration program [1]. This paper is motivated by the desire to understand the dynamics surrounding changes in a program's budgetary environment, and how best to accommodate or adapt in the face of those changes.

We focus on the process by which stakeholders within NASA and the US Congress may cooperate or compete to arrive at an affordable and politically sustainable funding level on a repeated yearly basis. In doing, we use game theory to model the process by which stakeholders interact to affect the NASA budget.

Because of the short-term nature of political choice, stakeholders tend to engage in short-term strategies when defining their interactions. Nevertheless, if a system is to be sustained over its design lifecycle, long-term strategies must also be employed. Brams' Theory of Moves (TOM) is therefore used to supplement traditional game theory, as a means of explicitly considering players' long-term strategic goals while examining their actions and motivations [2]. We then examine circumstances under which NASA and Congress may exercise "threat power" to motivate political decision making, yielding the counter-intuitive result that NASA's high valuation of its human spaceflight programs creates an incentive for Congress to provide NASA less funding than requested. This dynamic, over the long term, may undermine the program's political sustainability.

*Corresponding author. Tel.: +1 617 324 4551; fax: +1 617 258 0863.
E-mail addresses: david@mit.edu (D.A. Broniatowski), alweigel@mit.edu (A.L. Weigel).

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2. Analysis: theory of moves

In this paper, we examine the presence or absence of the TOM concept of "threat power", defined as "The ability to deter or compel an opponent to take action, at a loss to both players, given that the threatener will make a net profit in repeated play" [2]. Repeated play "…means that there is always later play that enables a threatener to recoup losses it may have incurred earlier in carrying out threats." [3]. A threatener may temporarily accept a loss so as to improve the final outcome. Practically speaking, this implies that a player may change position on a game matrix after the initial move has been made. Players then alternate, moving sequentially around the matrix, until one player decides to stop moving, thereby ending the game.

Consider the following game description: every year, Congress must decide on how it will budget funds to each of the executive branch agencies within the federal government. This situation may be modeled as a game played between Congress, which makes the decision to Save or to Spend and a given agency, following the policy direction of the president, who must decide to Deliver a Service or Not to Deliver a Service to the American public, and by extension, to Congress. Generally speaking, the situation may be described with the game matrix in Fig. 1.

We may use a variant of this game to describe the funding process for NASA after submission of the President's budget request. NASA provides the service of flying or grounding all its vehicles capable of human spaceflight. Fig. 2 shows four specific scenarios that are studied in this paper.

The first scenario, represented by Game One, the Incrementalism Game, describes a situation similar to that which prevailed before the loss of the shuttle *Columbia*, in which the Administration's high valuation of the human spaceflight capability provided by the shuttle program, and a Congressional incentive to keep costs low contributed to a budgetary environment marked by incremental budgeting and policy making [4,5]. Game Two, the Deterrence Game, describes a change in preferences brought about by exogenous events, such as the loss of *Columbia* and the reorganization of the Congressional Appropriations Committees. In this situation NASA may exercise threat power in order to achieve its desired outcome of obtaining funding from Congress for the purposes of maintaining human spaceflight capability. Game Three, the Uncertainty Game, explores those periods of time when space exploration was not a sufficiently high priority compared with other items on the national agenda. In this situation, NASA's budget request would be sufficiently high that, compared with other priorities, the benefits delivered to Congress by maintaining human spaceflight capability do not offset the costs. For example, between the *Columbia* tragedy and the reorganization of the Appropriations Committees, it was not clear whether Congress would endorse the construction of a new vehicle to maintain human spaceflight capability. Under these circumstances, NASA would be forced to continue to fly without receiving its funding request. Finally, Game Four, the Cessation Game, describes a situation wherein neither NASA nor Congress wishes to maintain human spaceflight capability. In this situation, both parties agree to terminate the program.

		Congress	
		Save	Spend
Agency	Deliver	(?,?)	(?,?)
	Not Deliver	(?,?)	(?,?)

Fig. 1. A generic game matrix for the agency–Congress game.

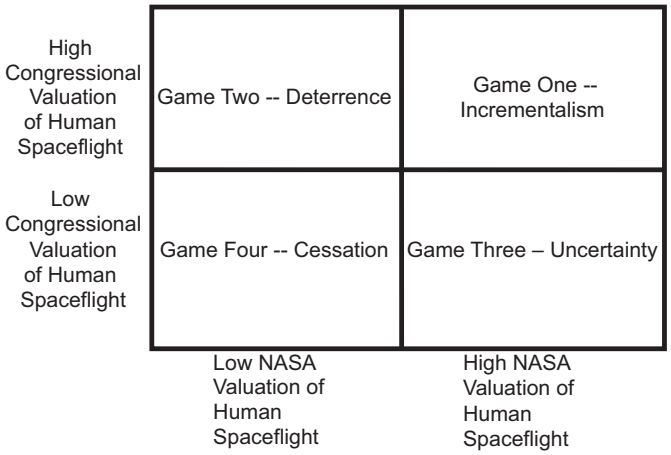

Fig. 2. NASA's and Congress' relative valuations of human spaceflight capability define the preference-ordering structure of each game. The four scenarios considered in this paper correspond to the four quadrants represented in this diagram.

These games are represented using an instantiation of the agency—Congress game mentioned above. In this NASA–Congress game, NASA may choose to Ground or Fly the vehicle providing human spaceflight capability (e.g. the Space Shuttle, or, later, the Orion). In addition, the president makes a yearly budget request for NASA to Congress. Practically, a decision by Congress to Spend indicates a willingness to fulfill or exceed the president's budget request for NASA, whereas a decision to Save indicates a lower, more incremental, level of funding that is more consistent with the previous year's budget request (cf. [4]). Similarly, a decision to Fly by NASA indicates a continued or increased level of activity from the previous year (such as continuing to fly the Space Shuttle), whereas a decision to ground, corresponds to a politically salient (e.g. newsworthy) reduction in activity by the agency (such as the decision to ground the Space Shuttle following the *Columbia* tragedy). In practice, NASA has not, and probably would not, publicly threaten to ground the Space Shuttle in response to a budgetary shortfall. Instead, a threat is more likely to be manifested as a technical argument that the Shuttle cannot be flown at the rate

		Congress	
Agency		Save	Spend
	Fly	(?,?)	(?,?)
	Ground	(?,?)	(?,?)

Fig. 3. A generic instantiation of the NASA–Congress game.

requested by Congress given the funding allowed, e.g. for reasons of safety. In the short term, NASA's technical expertise lends credibility to this argument, particularly during times of high uncertainty when experts employed by Congress simply do not have access to the data sources and facilities to which NASA is privy. We note, in Section 2.5, that the credibility of such threats may decrease over time if they are overused or not carried out. A generic version of the NASA–Congress game is shown in the matrix in Fig. 3.

2.1. Game One—Incrementalism

To define the parameters of this game, we assign the following preferences to each player, using a series of assumptions regarding NASA's goals in this situation. First, we assume that NASA prefers flying its vehicle to grounding it. We justify this assumption by noting that many of NASA's activities (such as the construction of the International Space Station and potential Hubble servicing missions) require a functional crew transportation vehicle in order to be executed. According to the agency's administrator, Michael Griffin, "…it takes about $4.5 billion to keep the shuttle going, whether you fly any flights or not" [6], a significant portion of which goes to maintenance costs and refurbishment costs on the ground [7]. Finally, we observe that, at the moment, maintaining the capability of human spaceflight may be said to be consistent with NASA's organizational goals, as the nation's only civil space agency [8]. Next, we assume that NASA prefers receiving funding to having its funding cut. Then we assume that NASA prefers flying its vehicle even when funding is not present. We justify this assumption based upon historical observation, wherein NASA has displayed a "can-do" attitude, perhaps compelling the attempt of complex undertakings when the resources required to support them are not present. Indeed, following the *Columbia* tragedy, NASA was characterized as "an organization straining to do too much with too little." [9], indicating that it has harbored a preference for action, even in the absence of sufficient budgetary resources. These assumptions are sufficient to define a ranked set of preferences for NASA for each of the four possible outcomes of the incrementalism game:

(Fly, Spend) > (Fly, Save) > (Ground, Spend) > (Ground, Save)

These preferences for NASA may be ordered such that 4 (the most preferred outcome) corresponds to (Fly, Spend); 3 corresponds to (Fly, Save); 2 corresponds to (Ground, Spend) and 1 (the least preferred outcome) corresponds to (Ground, Save).

Next, we must define the preference-ordering structure for Congress. We begin by assuming that Congress prefers to possess a domestic human spaceflight capability. Reasons for such a preference are manifold, including, but not limited to, the national pride and prestige associated with a national spaceflight program, as well as more locally oriented interests, such as the revenues and employment opportunities that a large federal program can bring to individual Congress members' districts [10]. For example,

> The Space Shuttle program occupies 640 facilities, utilizes over 900,000 equipment line items, and directly employs over 2000 civil servants and more than 15,000 work-year-equivalent prime contractors, with an additional 3000 people working indirectly on Space Shuttle activities at all NASA Centers. Thousands more are employed at the subcontractor level in 43 states across the country. The total equipment value held by the Program is over $12 billion. The total facilities value held by the Program is approximately $5.7 billion (approximately one-third of the value of NASA's entire facility inventory), mostly at the field centers. There are also approximately 1500 active suppliers and 3000–4000 qualified suppliers that directly support the Space Shuttle program. [11]

Those members of Congress with NASA employees in their districts have a distinct electoral incentive to maintain a domestic human spaceflight capability, namely keeping their constituents employed and maintaining existing revenue streams in their state. Other incentives include the achievement of foreign and scientific policy objectives, as illustrated by the following statement by Senator Barbara Mikulski (D-MD), Ranking Member of the Senate Appropriations Committee, Subcommittee on Commerce, Justice, Science and Related Agencies, which includes NASA:

> The United States of America should always have its own access to space. The space station, too, we need to be able to finish that, keep our commitment to our international partners, and keep it as a premier research facility. And, of course, then there is Hubble. Everyone knows my position on Hubble. And I believe it's been the greatest telescope invention since Galileo himself stood on that rooftop in Florence.[12]

Congress prefers that the vehicle fly rather than that be grounded. We assume that, given a certain vehicle state (either flying or grounded), Congress will prefer saving its money for other priorities. Thus, given that a domestic vehicle (such as the Space Shuttle or the upcoming Orion) is already flying, Congress will not provide additional funding for human spaceflight, since the need for human

spaceflight is already fulfilled. Maslow describes this phenomenon in psychological terms as follows:

> …a want that is satisfied is no longer a want. The organism [in this case, a member of Congress] is dominated and its behavior organized only by unsatisfied needs. If hunger is satisfied, it becomes unimportant in the current dynamics of the individual [13].

Van Dyke elaborates, "[Political figures] tend to speak of those values or interests that are threatened or that seem to be in need of attention, and they tend to forget about values and interests that seem to be assured. Sometimes there seemed to be complete unawareness of certain values and interests and complete insensitivity to developing dangers."[14]. Similarly, given that the vehicle is grounded, Congress will not expend extra resources if those resources will not generate human spaceflight capability. Therefore, Congress tends to prefer to save its resources if spending them will not alter the outcome.

Finally, to fully define the preference structure, we assume that Congress prefers to pay to maintain human spaceflight capability rather than have it grounded. We justify this assumption by observing that, following the *Challenger* and *Columbia* tragedies, Congress has continued to provide funding to NASA for human spaceflight activities, under the assumption that the Shuttle would return to flight. In fact, following the *Challenger* explosion, NASA requested, and was provided with, additional funding in order to build a new Shuttle, *Endeavour*, demonstrating a willingness on the part of Congress to provide supplemental funding when human spaceflight capability is endangered. With these assumptions, we can now define Congress's preference structure in the Incrementalism Game:

$$(\text{Fly}, \text{Save}) > (\text{Fly}, \text{Spend}) > (\text{Ground}, \text{Save}) > (\text{Ground}, \text{Spend})$$

As noted above, these Congressional preferences may also be ordered from 4 (the most preferred) to 1 (the least preferred), such that (Fly, Save) is 4; (Fly, Spend) is 3; (Ground, Save) is 2; and (Ground, Spend) is 1. The preference orderings of NASA and Congress, when taken together, result in the game matrix seen in Fig. 4. NASA's preference is the first number in each cell, whereas Congress's preference is the second number. Each row represents a strategic choice for NASA (i.e. Fly or Ground), whereas each column represents a strategic choice for Congress (i.e. Save or Spend).

		Congress	
		Save	Spend
Agency	Fly	(4,3)	(3,4)
	Ground	(2,1)	(1,2)

Fig. 4. The matrix representing Game 1, the Incrementalism Game. The Nash equilibrium is boxed. The shaded area represents Congress' compellent threat.

2.1.1. Game One—analysis

A brief inspection of the matrix in Fig. 4 yields the information that the Nash equilibrium solution of this game is at (Fly, Save), as indicated by the box.[1] In other words, NASA can do better by flying than by not flying, and Congress can always do better by saving money than by spending money. Practically, (Fly, Save) suggests that NASA continues to fly its vehicle at the pace expected by Congress and the president. This might entail a slight slip in vehicle launch schedule that is not politically salient, or a reallocation of funds from other NASA programs to offset launch costs. Congress, on the other hand, provides NASA with at most an incremental increase in funding, potentially at a lower rate of increase than that provided to other, more politically salient agencies. This outcome is consistent with the situation described in the CAIB report, which describes NASA as "an organization straining to do too much with too little", and engenders a "zero-sum" mentality within the agency whereby individual programs must compete with one another for a fixed amount of Congressional funding [9].

From a Congressional perspective, a reduction in NASA's budget may be slight. Nevertheless, from the perspective of an individual program, it could mean the difference between success and cancellation. Program components within administrative agencies typically undergo periods of non-incremental behavior in response to seemingly incremental changes at the agency level [16].

Fig. 5 illustrates monetary shifts below the agency level. For example, between FY2002 and FY2003, a $1 billion shift in the NASA budget from "Science, Aeronautics and Technology" toward "Human Space Flight" may be observed. In FY2004 much of this funding is restored [17]. This suggests that NASA's attempts to meet Congressional expectations by reallocating internal resources can have negative consequences for individual programs of lower priority. Congress, on the other hand, has often responded to NASA's reallocation attempts by using program-specific language and budget line-items to extend legislative authority and appropriations to individual programs. Although this puts legal limits on the reallocation of funds described above, it strengthens the game dynamics described in this paper by extending Congressional oversight, and therefore incrementalism, to the programmatic level.

Having defined the game matrix, we now ask whether, given these conditions, NASA possesses any threat power. Given this payoff matrix, NASA would only attempt to

[1] The Nash equilibrium is defined as the "profile of strategies such that each player's strategy is an optimal response to the other players' strategies" [15]. In the specific context of the games discussed below, the Nash equilibrium can be identified by examining each player's best response to its opponent's strategy. The location where the best responses coincide is the Nash equilibrium.

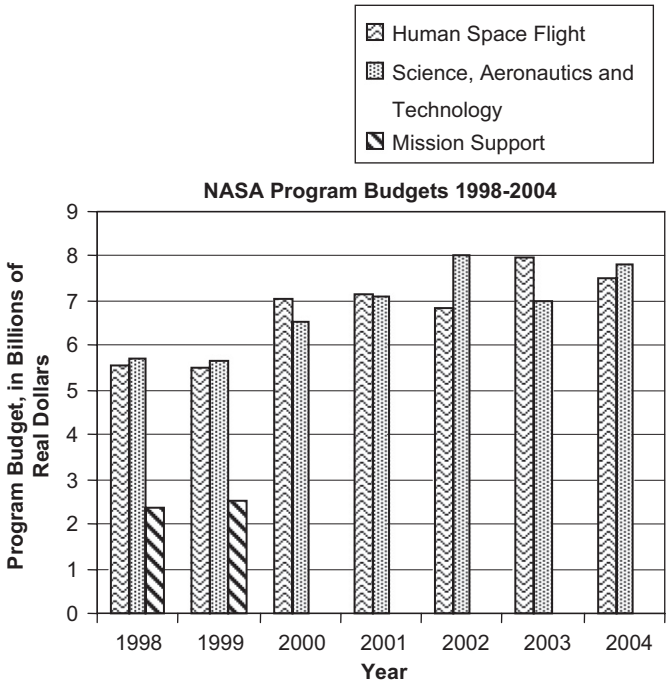

Fig. 5. NASA's budget as granted by Congress, in real dollars (NASA 2006) [17].

enforce the (Fly, Spend) outcome, since that is the only outcome that is better than the Nash equilibrium-enforced status quo. If Congress were to decide to cut human spaceflight funding below the amount requested by the president, NASA could exercise this threat through a technical argument linking scarcity of resources to a need to ground its vehicle, e.g. for safety reasons. This is classified as a deterrent threat since NASA is attempting to prevent Congress from taking an action by threatening retaliation [3]. We note that although this threat is real (Congress would suffer a loss in utility if NASA decided to ground the Shuttle), it is not rational, since NASA would also suffer a reduction in utility. Therefore, this threat is not credible and NASA does not possess any power to enforce this deterrence.

Next we explore whether Congress wields any threat power. We begin by noting that Congress would prefer to enforce the Nash equilibrium outcome of (Fly, Save). Congress could employ a threat to prevent NASA from grounding its vehicle by refusing to move from its position of refusal regardless of NASA's actions. This type of threat is classified as compellent since Congress is trying to compel NASA to fly by refusing to move. Here we note that this threat is both real (since NASA stands to lose from grounding the Shuttle) and rational (since Congress will only reduce its payoffs by deciding to increase funding). Thus Congress possesses sufficient power to enforce its desired outcome, namely the Nash equilibrium outcome, in repeated play, suggesting the presence of a chronic funding shortage. We feel that this accurately describes the situation surrounding the Shuttle Program before the *Columbia* tragedy. Congress, lacking any direct incentive to increase the budget for human spaceflight, would simply renew or, at best, incrementally increase the previous year's human spaceflight budget, effectively causing a reduction in constant-year dollars as inflation decreases buying power [4]. To make matters worse, as a reusable vehicle fleet gets older, one can expect its recovery and refurbishment costs to increase substantially, leading to a tighter budgetary environment [7]. These factors, when combined with the chronic cost overruns and rushed schedule for completion of the International Space Station, contributed to the organizational difficulties that eventually led to the *Challenger* and *Columbia* tragedies [5,9].

2.2. Game Two—Deterrence

Consider, now, the case in which NASA no longer subscribes to the "can-do" attitude. Instead, if NASA is not receiving sufficient funding, it prefers to ground its vehicle, fearing for astronauts' safety in the face of inadequate resources. This change in preferences could be brought about by a shock, such as the *Columbia* tragedy, whereby priorities within the agency and/or the White House are redefined. This may be justified as a precaution taken during a period of extreme sensitivity to the risks involved in flying astronauts in a vehicle that is perceived as unsafe. These preferences generate the game matrix seen in Fig. 6.

2.2.1. Game Two—analysis

Again we begin by identifying the Nash equilibrium of the game. We find that it is located at the "breakdown outcome" of (Ground, Save), so-called because it is the state resulting from a breakdown of negotiations between Congress and NASA. If each player were to think only of their near term interests, the future of human spaceflight would be called into serious question. In this case, Congress would essentially give up on human spaceflight as an endeavor that does not deliver sufficient value to fully fund the president's request, whereas NASA, fearing for astronauts' safety in a scarce budget environment, would refuse to fly the vehicle.

Analyzing this game for threat power yields a very different result. As before, we examine the case where NASA tries to enforce the (Fly, Spend) outcome using a deterrent threat. Here the threat is real, since Congress prefers to see the vehicle flying than to see it grounded, and

		Congress	
		Save	Spend
Agency	Fly	(4,3)	(1,4)
	Ground	(3,1)	(2,2)

Fig. 6. The matrix representing Game 2, the Deterrence Game. The Nash equilibrium is boxed. Arrows represent the deterrent threat that would be employed by NASA in the event Congress chooses not to fund.

the threat is rational, since NASA prefers to ground the vehicle in the case of no funding. NASA therefore possesses credible deterrent threat power. In addition, we note that Congress no longer has compellent threat power. Although Saving is still a dominant strategy for Congress, Congress's threat is no longer rational since it can do better by acquiescing to the president's request for more NASA funding. These results highlight the effects that changing one player's preference ordering may have on the outcome of the game. To begin with, it is important to note that NASA, in changing its preferences, affects Congress's threat power. In other words, Congress's threat in the Incremental Game is rational only because NASA prefers to keep its vehicles flying in spite of insufficient funding. This yields the counter-intuitive result that NASA's high valuation of its human spaceflight program allows Congress to under-fund the program. NASA, as the source of technical expertise evaluating the feasibility and safety of human spaceflight, might be able to elicit increased funding for the program if it can be demonstrated that such funding is necessary to ensure crew safety and vehicle reliability. It will be noted later that there is a practical limit to how much money Congress might be willing to spend.

2.2.2. *How preferences are signaled and interpreted*

NASA Administrator Michael Griffin has effectively acted to change NASA's preferences, whereas the *Columbia* tragedy and incipient Shuttle retirement threatens uncertainty of the breakdown outcome:

> Griffin wants to fly the proposed new spacecraft as soon as possible once the space shuttle fleet is retired in 2010 – avoiding a four-year gap in which the United States would have no way to launch astronauts [18].
> NASA hopes to pay the tab from its scheduled modest budget increases [19].

In this situation, a signal is being sent advocating that Congress at least approve, if not improve upon, NASA's budget for the next years and threatening Congress with a lapse in human spaceflight capability that, if unchecked and under-funded, could become debilitating or, at worst, permanent. Acceleration of Orion development, although eliminating this gap, tends to compound the budget issue, making the threat more real and more credible to Congress.

Congress, on the other hand, sends signals through resolutions, statements to the press, etc. Many prominent members of Congress have expressed their support for NASA's human spaceflight activities [20,21]. Prominent Senators from both political parties have voiced their support for NASA's human spaceflight activities, and for minimizing the time between Shuttle retirement and Orion launch [12]. In addition, Senator Hutchison and her Democratic counterpart, Ranking Member Sen. Bill Nelson of Florida, submitted an amendment to the FY2006 Defense Authorization Bill "expressing the Sense of the Senate regarding the critical nature of human space flight to America's security"[22]. This amendment includes the following language:

> It is the sense of the Senate that it is in the national security interest of the United States to maintain uninterrupted preeminence in human spaceflight [23].

These statements reflect a high valuation of human spaceflight on the part of Congress, thereby enabling a real threat in the prospect of the loss of American human spaceflight capability. In addition, this threat is credible since current plans call for the retirement of the Shuttle by 2010. It is worth noting that the Senate has considered legislation that would require that the Shuttle fly until a replacement becomes available, although this legislation has not been passed into law [24]. This language, which seems aimed at reducing the credibility of NASA's threat, suggests that the Senate is aware of the vulnerability of their position. A later bill, S. 1281, somewhat diluted this requirement, stating that "there not be a hiatus between the retirement of the space shuttle orbiters and the availability of the next generation US human-rated spacecraft", omitting any specification of how this hiatus would be eliminated [25]. A requirement to keep the Shuttle flying until the Orion is developed could, in principle, allow Congress to continue behaving in an incremental fashion with regard to human spaceflight, since a delay in the Orion because of lack of funding would no longer be a present concern. Indeed, rather than fund the full development of a new vehicle, Congress could simply provide the additional funding required to keep the Shuttle flying while chronically under-funding Orion development. This would be a return to the pre-Columbia funding paradigm. Nevertheless, the events surrounding the Shuttle *Discovery*'s return to flight on 26 July 2005 have further served to increase the credibility of NASA's threat to ground the fleet for technical reasons [26].

Senator Hutchison, in a statement preceding a floor vote on S. 1281, the Senate version of the NASA reauthorization bill that "authorizes NASA appropriations in excess of the President's budget request", publicly recognized the link implied by the Deterrence Game [25]. Referencing the recently released NASA Exploration Systems Architecture Study, Senator Hutchison stated that:

> The key to [Orion] acceleration is largely a question of resources, and sufficient funding could enable an even earlier operational date, possibly closing the potential gap in spaceflight capability altogether [25].

These responses demonstrate the power a valid technical rationale may wield in Congressional decision making.

2.2.3. *The power of exogenous factors*

This analysis illustrates the power of exogenous factors (i.e. those that are beyond players' control in the game, such as factors that change player preferences) in determining the outcome of a game. As seen in the first example, the Nash equilibrium outcome, reinforced by

Congress's threat power, predicted that human spaceflight would be under-funded. Furthermore, TOM predicts that this outcome would occur on a repeated (in this case, yearly) basis. Following the change in preferences, we note that a new paradigm has arisen whereby NASA, by acting proactively, may ensure the funding profile for human spaceflight presuming it presents an adequate rationale. This outcome will be repeated for as long as NASA is willing and able to carry out its deterrent threat. This suggests a new set of parameters governing the funding profile following the change in preferences. In the event that NASA's preferences were to return to those seen before the accident, the outcome would revert back as well. This model therefore supports McCurdy's identification of incrementalism as the *modus operandi* within NASA's internal political structure [5]. In addition, the presence of short, non-incremental time periods during which the parameters of the incremental model shift may be interpreted as "political shocks" or "policy punctuations" in between incremental periods [27,28].

2.3. Game Three—Uncertainty

Next, we consider another change to the set of preferences. In this case, we examine the case in which Congress prefers saving money for other endeavors, even at the expense of human spaceflight, to spend the money required to keep humans in space. This might occur in the circumstance in which a determination has been made by Congress that the value delivered in maintaining the Shuttle program is simply not sufficiently high to warrant the funds requested by NASA. Alternatively, Congress might simply decide that human spaceflight activities are no longer within the nation's political interest. This situation is described by the game matrix in Fig. 7.

2.3.1. Game Three—analysis

In this case, we note that Congress once again has compellent threat power. NASA, lacking a threat that is neither real nor rational, has no credible threat available, and will simply default to flying the Shuttle with insufficient funding. This game assumes, as before, that NASA prefers flying the Shuttle without funding. It is worth noting that outcomes here are indistinguishable from those in the first example, suggesting that NASA may not be able to determine the preferences of Congress if it is receiving insufficient funding. In effect, by refusing to give NASA the requested funding, Congress sends an ambiguous signal. Fig. 8 illustrates the uncertainty faced by NASA in this situation.

Although the Shuttle was grounded in 2003 following the *Columbia* tragedy, it was only in 2005 that NASA, under the leadership of its newly appointed administrator, sent a signal indicating that long-term human spaceflight capability might be placed in jeopardy. Indeed, a comparison of NASA's human spaceflight budget for FY2004 awarded by Congress with the president's request shows that the president's budget request was under-funded by $253 million for human spaceflight alone [29,30]. FY2005 tells a different story: whereas the president requested $16.2 billion in total for NASA, the Senate awarded $16.4 billion, including $800 million in emergency funds. In contrast, the House of Representatives only awarded $15.1 billion in total, specifically awarding NASA $959.6 million less than what had been requested for human spaceflight. This constituted a $23.9 million reduction over the FY2004 appropriation [30,31]. Although NASA, and by extension human spaceflight programs, eventually received full funding, this required extraordinary measures on the parts of President George W. Bush and then House Majority Leader Tom DeLay (R-TX) [32]. President Bush even went so far as to threaten to veto any budget that was not congruent with his funding request for NASA, an unprecedented move in space policy [33]. At a time when the Shuttle was grounded and the future of American human spaceflight was uncertain, these moves by the House of Representatives called into question Congressional valuation of the human spaceflight program, suggesting that NASA simply did not have the threat power necessary to enforce its budget requests. The situation changed in February 2005, when Leader DeLay orchestrated the reorganization of the House Appropriations Committee. As a result, responsibility for NASA spending was shifted from what had been the Veterans' Affairs & Housing and Urban Development (VA-HUD) subcommittee to the Science, State, Justice and Commerce Committee [34]. This type of event is a rarity in Congressional relations, and may be considered enough of a political shock to have changed Congressional preferences in favor of promoting human spaceflight. This, in turn, yielded Griffin the opportunity to take advantage of

		Congress	
		Save	Spend
Agency	Fly	(4,2)	**(3,4)**
	Ground	(2,1)	(1,3)

Fig. 7. The matrix representing Game 3, the Uncertainty Game. The Nash equilibrium is boxed. The shaded area represents Congress' compellent threat power. Note that this game has the same basic structure as the Incrementalism Game.

		Congress	
		Save	Spend
Agency	Fly	(4,?)	**(3,4)**
	Ground	(2,1)	(1,?)

Fig. 8. NASA, lacking complete information about Congressional preferences, is unable to distinguish between the Incrementalism Game and the Uncertainty Game.

the newly available threat power coincident with his arrival. It remains to be seen whether shifting priorities, such as the expense associated with national disasters like Hurricane Katrina and the Gulf war, have caused another re-evaluation of the value of human spaceflight [35].

2.4. Game Four—Cessation

Finally, for completeness, we consider the case in which Congress puts a low valuation on the Space Shuttle program and NASA prefers to ground its vehicle in the absence of sufficient funding. This game is represented by the matrix in Fig. 9.

We note that, in this case, neither player possesses threat power of any kind. As a result, neither player is able to enforce a desired outcome. In addition, the Nash equilibrium of this game is also the breakdown state of (Ground, Save). The intuition for this result is that if neither NASA nor Congress is interested in maintaining human spaceflight, it will be put on hold. For repeated games, this implies cancellation of the human spaceflight program.

2.5. Analysis of signals: imperfect information

These four examples, when taken together, may provide some insight into why NASA has in the past been unwilling to carry out a deterrent threat. Suppose that NASA does indeed value human spaceflight highly. In this case, Congress possesses the threat power to restrict NASA funding regardless of the Congressional valuation. As Fig. 10 demonstrates, without complete information NASA would be unaware of Congress's valuation of human spaceflight.

NASA takes the risk of attempting to carry out an incredible threat that might result in the loss of human spaceflight capability. If, on the other hand, NASA makes a deterrent threat and fails to enforce it, this may negatively affect NASA's ability to make future credible threats. Thus, NASA has an incentive to act in accordance with its valuations. NASA's actions send Congress a signal indicating its valuation of the human spaceflight program. On the other hand, in the absence of a threat from NASA (or exogenous forces, such as a presidential veto threat), Congress will seek to reduce funding, regardless of its valuation of the human spaceflight program. Therefore,

		Congress	
		Save	Spend
Agency	Fly	(4,2)	(1,4)
	Ground	(3,1)	**(2,3)**

Fig. 9. The matrix representing Game 4, the Cessation Game. The Nash equilibrium is boxed.

		Congress	
		Save	Spend
Agency	Fly	(4,3)	(1,4)
	Ground	(3,1)	**(2,2)**

Fig. 10. NASA, lacking complete information about Congressional preferences, risks terminating human spaceflight capability if a non-credible deterrent threat is exercised. Here, NASA must distinguish between the Deterrence Game and the Cessation Game.

any signal sent by Congress is ambiguous, relegating NASA to a position in which it does not possess sufficient information.

2.6. Implications for political sustainability

These results provide insight into strategies for political sustainability. As technical experts, NASA could make a credible technical case for the necessity for more funding. In order for the deterrent threat to be successful, threats to NASA's technical credibility with Congress, such as a vehicle failure or promises that have not been kept, must be held to a minimum. Therefore, a deterrent threat should be used sparingly, and only when necessary. If NASA's technical credibility is undermined, a situation similar to that described in Game Three, the Uncertainty Game, is likely to result.

As mentioned previously, NASA has imperfect information regarding Congress's willingness to fund. This suggests a risk in advocating too strongly for a higher budget in times of political uncertainty (e.g. in the absence of strong presidential support). If NASA were able to correctly assess the Congressional interest, the uncertainty might be reduced.

3. Conclusion

Political sustainability is intimately tied up with goals, values and interests. In particular, a program will be sustained if it is delivering value to the stakeholders who are contributing the resources necessary to keep it going. Value delivery is a necessary condition, but it is not a sufficient condition. This is particularly true in situations in which there are limited budgetary resources and many worthy goals to address with those resources. Such a situation is encountered on a regular basis by any number of government programs attempting to obtain federal funding from a Congress that has several options to choose from with regard to where to allocate funding. An agency or program, on the other hand, has only one source of funding, namely Congress.

The above model demonstrates that a program is unlikely to receive its requested level of funding if it is perceived that the program can maintain a consistent pattern of operation without it. In particular, this model

examines the situation in which NASA provides Congress (and by extension, the American people) with human spaceflight capability. Until that capability is put under threat, Congress is unlikely to fully support a funding request for human spaceflight, and may reallocate funding in the face of more pressing concerns. The intuition for this conclusion is that Congress, already receiving human spaceflight capability at a lower funding level, may tend to take it for granted. Put simply, Congress will not pay more to receive what it is already getting. If, however, there is a perception that the capability is under threat, Congress will be willing to provide support up to the point where a determination is made that the benefits no longer outweigh the costs. This has implications for an agency's advocacy to Congress: in order to maintain political sustainability, a successful case must be made on a yearly basis for why funding is necessary not only to accomplish new objectives, but also to maintain existing capabilities. If the objectives of NASA do not coincide with those of Congress, a dearth of funding will result. Future work should therefore focus upon determining the goals and interests of Congress and, indeed, of all stakeholders involved in the resource allocations process, in order to determine their crucial needs and how best to fulfill these such that the prospect of their loss is sufficient to encourage sustained support.

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