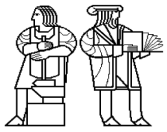

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DECISION-MAKING IN THE POLITICAL AND TECHNICAL ENVIRONMENTS

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Mutual misunderstanding between decision-makers in the political and technical environment leads to programs that experience cost overruns, schedule delays and, often, cancellation. This paper compares and contrasts the determinants of decision-making in the technical and political realms, with the intention of demonstrating how these decisions translate to cost, schedule and performance parameters. Studies of those elements that are most salient to the policy maker are informed by the political science literature. In particular, studies of administrative, bureaucratic and Congressional decision-making are instructive in determining how an engineering system interacts with the political realm. So as to lend concreteness to this analysis, we focus on NASA's interactions with Congress surrounding the Vision for Space Exploration, announced by President Bush on January 14th, 2004.

Roots and Branches

Perhaps the primary difference between an engineering decision and a political decision is the method by which conclusions are achieved. Whereas traditional engineering strives for rationality and optimal trades between clear objectives, political decisions are largely marked by compromise aimed at building supporting coalitions. Furthermore, the complexities of the political environment impose considerable limitations on rational choice. (Lindblom 1959) discusses these limitations in detail by identifying two paradigms for approaching a problem. The first, which he calls the "Rational-Comprehensive" or "root" method, is a description of a rational/positivist approach in which a decision maker will begin by clarifying values or objectives and then formulate comprehensive policy through means-end analysis. This method, representing the archetype of ideal engineering design, requires evaluating every alternative in a particular decision space and, although it is theoretically mathematically tractable, it requires a clear definition of goals and, perhaps more importantly, a well-defined utility function that can be used to distinguish between outcomes. When executed properly, a rational design yields a result that maximizes some performance metric within the basis of well-understood scientific theory. Thus, reliance on theory is the cornerstone of the root method.

Lindblom argues that genuine execution of the Rational-Comprehensive method for all but the simplest problems lies beyond the memory capacity of any human being. Engineers, generally possessing design goals, can circumvent these

limitations using tools designed to identify an optimal design upon the basis of generalizable theory. The complexity of the political environment, on the other hand, is currently beyond the reach and understanding of any encompassing predictive theory. Furthermore, the existence of multiple independent intelligent actors suggests that any high-fidelity prediction is naturally intractable. In order to describe decision-making in this regime, Lindblom defines the method of "Successive Limited Comparisons", or the "branch" method, which argues that the decision making process is one in which identification of values and goals are not separate from empirical analysis. Similarly, means and ends are not distinct, implying that a goal is generally not well-defined. Furthermore, since means-ends analysis is limited to those few alternatives that the decision maker can simultaneously consider, possible outcomes, policies and values are often not considered at all. Lindblom claims that, in the vast majority of cases, a decision maker will rely upon the branch method due to the fact that the computational power and data that are required to achieve the root method are generally not available. This represents the standard archetype of political decision-making. Resulting policies are therefore likely to be suboptimal from a purely rationalist standpoint. Where engineering design is aimed at maximizing lifecycle performance, politics aims to maximize immediate desirability so that an item may be cleared from the policy-maker's agenda.

The method of Successive Limited Comparisons highlights the importance of a providing a diversity of viewpoints to decision makers since they will only be able to choose between the arguments that are directly available and salient to them. This provides an implicit justification for a group to undertake advocacy activities since, without them, decision makers will naturally tend to forget about or ignore the viewpoints and goals that that particular group represents. Perhaps more importantly, it indicates that an actor who controls the flow of information concurrent with technical expertise possesses some degree of control over the final decision that is made. It is exactly this type of control that any administrative agency with technical expertise, can exercise in its interactions with Congress.

Salience and Attention

The stage is set for a description of the policy-making process as a battle between interest groups for salience within decision makers' limited attention resources. In the face of numerous pressing concerns from all sides, a policy maker will by necessity choose those alternatives that are directly within reach and most likely to simultaneously satisfy the largest number of stakeholders in the short-term. This suggests an environment of pure competition between interest groups wherein each group attempts to dominate the attention of the decision maker. Nonetheless, it is worth noting that the branch method also allows for agreement on policies without a necessary agreement on the goals that those policies might imply. Therefore, cooperation and coalition-building between groups that might

both stand to gain from a particular policy occurs, even though these groups might have completely different viewpoints and opposing goals. A savvy politician builds consensus one step at a time, helping various groups achieve intermediate goals, to the extent that those goals are congruent with his/her ultimate goal.

The ability to agree on means when ends are in stark contrast is foreign to the traditional engineering mentality, which typically identifies a set of design goals and trades design parameters against this goal until exogenously-imposed requirements are fulfilled. Since political decision-makers often set, or must at least approve, the high-level goals of a publicly-funded endeavor, the above argument provides an explanation for why publicly-funded systems are subject to changing policy priorities. This, in turn, calls for an examination of how political goal-setting takes place.

Goals and Values

(Van Dyke 1962) follows Lindblom's lead in suggesting that values may be defined as either "goal values", which are necessary in and of themselves and "instrumental values" that are necessary to the performance of another goal. He explains that a "goal value" is defined by the particular organization or individual in question, and that one organization's goal value might be another's instrumental value. This is particularly true for engineering systems, where the design goal of the system is likely to deliver instrumental value rather than directly serving a policy-maker's goal values. A case in point of this dynamic is the goal value of space exploration championed by NASA. Depending on the desires of the President and Congress of the time, this goal value was generally instrumental towards accomplishing some other goal. For example, the Apollo program was instrumental to defeating the Russians in a Cold War space race; the Shuttle program was instrumental as a high-tech re-election campaign; the International Space Station was instrumental first to demonstrate to the Soviet Union the resolve of the free world, and later, to employ Russian scientists who might otherwise contribute to nuclear proliferation. Thus, NASA's relevance to a political decision-maker increases or decreases to the extent that space exploration is instrumental to the goal values of the Presidency and Congress.

Stakeholders' goal values may be ranked using the *Hierarchy of Needs* proposed in (Maslow 1970).

Figure 1: Maslow's "hierarchy of needs". An individual's attention is immediately diverted towards its most basic need when that need is endangered. Image sourced from (Maslow).

Thus, an instrumental goal is more likely to get support when it is linked to a goal value that is low on the pyramid, such as "security" or "safety". This has implications for coalition building because an interest group might be willing to support a given policy even though that policy might not be directly related to that group's "goal value". If a case can be made that the policy, as executed, would serve as an instrumental goal for that interest group, then that interest group may provide support. Similarly, if a seemingly irrevocable conflict should arise between interest groups, a solution might be found by redirecting attention away from the value goals in conflict toward those instrumental goals that are held in common. To paraphrase Charles Dudley Warner, politics does indeed make strange bedfellows.

Van Dyke's work has important implications for the designer, suggesting that technical expertise in administration is relied upon to promote politically selected values, an argument also suggested in (Jasanoff 1987). In the case of NASA, this suggests that any exploration architecture must actively seek relevance to current national policy. This further suggests that activities that are not directly relevant

will not receive attention and will, at best, be left "idling" with incremental funding and, at worst, be cut. At the same time, NASA has a unique role as the technical experts in all things related to their mandate in civil aerospace. As such, they are in a unique role to control the flow of information. Thus, once a congressional directive is issued, NASA has enormous power in determining the implementation for how that directive will be fulfilled and in what options are under consideration. Whereas Maslow's hierarchy suggests that salience may be achieved by putting a given value under threat, Van Dyke suggests that salience may be achieved through direct relevance to existing national priorities. This further suggests that the designer should explicitly consider the goal values that the system to be designed is intended to achieve. This is complicated by the fact that there are often many goal values – at least one for each stakeholder group – and that they may be in conflict. In this case, Van Dyke suggests that the best course of action is to alert the stakeholders of the potential conflicts and of the tradeoffs that will have to be made. This gives the stakeholders a sense of responsibility and ownership in the process, and allows for ease of negotiation. In the words of Otto von Bismarck, "politics is the art of the possible". It is therefore the role of the technical expert to outline the space of possible options. At the same time, efforts must be undertaken by supporters of a given system design to illustrate to political decision-makers the consequences of changing resource allocations.

It is worth noting that linkage to a high-salience agenda item, such as a particular national security concern, is a double-edged sword. Whereas such a linkage is likely to ensure the program significant support in the short-term, eventual solution of the high-salience problem is likely to lead to the determination that so much support is no longer necessary. On the other hand, linkage to an item that is of lower salience, such as an ongoing mission of scientific discovery, is likely to receive less funding on an annual basis but is also likely to be more robust to large swings in support.

The above analysis illustrates some motivations behind the swiftly-changing nature of the political process. The political system is sufficiently complex that it likely lies beyond any current predictive capacity. Nonetheless, it is possible to outline certain patterns of behavior that seem to occur with regularity. (Simon 1964) notes that although individual members of an organization might be very different people, they must fulfill their organizational "roles". For example, an Office of Management and Budget (OMB) examiner will seek to reduce costs and increase efficiency regardless of the person holding that role. The role therefore defines, to some extent, the actions of the individuals holding that role. Although personal goals do play a part in organizations, Simon notes that actions on the basis of personal goals will be small compared to actions on the basis of role goals because of training and self-selection. One can therefore infer an

organization's goal simply from its behavior, since any action not taken is prevented by a constraint. As such, we may draw general conclusions about the behavior of specific types of political actors. Indeed, agencies often rely on this quasi-predictable type of behavior when generating budgetary strategy.

(Kingdon 2003) outlines the roles of several major players within the U.S. government. This book is a valuable source for any student of policy, providing quantitative and anecdotal evidence to support descriptions of policy actors and the types of power that they wield. A model of how policies are generated is then created, based upon the ethos of (Cohen, March et al. 1972), which essentially describes organizational choice as occurring in an almost unpredictable semi-chaotic fashion, driven by a complicated interplay of multiple streams. In particular, Kingdon characterizes three "streams" of policy-making – the Political Stream, the Policy Stream, and the Problems Stream. The Political Stream, composed of "such things as public mood, pressure group campaigns, election results, partisan or ideological distributions in Congress, and changes of administration", characterizes that element of the policy-making process that is colloquially identified as "politics". The author explains the events of the Political Stream in some detail, describing it as a promoter of agenda items. The Policy Stream, on the other hand, is largely dominated by specialists in a certain field, such as agency civil servants. Solutions are generated, often without specific problems to which these solutions might be attached, generating the phenomenon of "solutions looking for problems". The primary role of the members of the Policy Stream is to narrow the set of all possible policy proposals into a short list of those that are both technically feasible and may be seriously considered. Kingdon further classifies policy communities within this stream as either fragmented or non-fragmented, noting that fragmented communities, those that are composed of many diverse interests, are generally less successful because of their lack of coordination. This point is supported by the work of (Olson 1984). Kingdon draws parallels between the fragmentation of a policy community and the fragmentation of the associated political system, arguing that more fragmented systems require more overhead coordination. Finally, there is the Problems Stream, in which specific issues become taken up by the public and are brought to the attention of the electorate. This stream is largely influenced by leading indicators that policy makers can use to measure the efficacy of a problem's solution. Problems that are not initially salient are brought to policy makers' attentions through "focusing events", such as crises, accidents or symbolic actions. Kingdon describes the coming together of these three streams as the creation of a "policy window" through which a successful policy entrepreneur can achieve a lasting action. For a specific issue, these windows are generally short-lived and must be acted upon promptly when discovered, thus necessitating that a successful policy entrepreneur be constantly prepared to take advantage of changing circumstances. For a given technical design, this suggests

that policy advocates will attempt to justify the system as a potential solution to an existing problem for which the system might previously have had no requirement.

Budgetary Politics

(Wildavsky 1964) is a detailed studied of agency-Congress interactions and the attempts that agencies might use in order to assure and/or increase their yearly budget. Casting budget requests as well-thought-out strategies made by each agency, a budget request is generally aimed at getting the agency the maximum amount of money requested, but not so much that the request loses credibility. Arguing that "If politics is regarded in part as conflict over whose preferences shall prevail in the determination of national policy, then the budget records the outcome of this struggle", Wildavsky characterizes executive branch agencies as organizational actors whose primary goal is to maximize their budget on a yearly basis. In his analysis, he identifies numerous strategies used by each agency in this endeavor, devoting an entire chapter to their description. Many of Wildavsky's strategies are insightful and the savvy system architect may make use of them to incorporate design rules that can aid the political supporters of the program.

Budgetary Incrementalism

Wildavsky argues that limited Congressional attention and budgetary resources, combined with each agency's simultaneous attempt to defend or increase its budget will result in "incrementalism", a state wherein each year, a budget may only increase or decrease slightly relative to the previous year's baseline. This has significant implications for technical design in that one can not expect any sharp spikes in funding, even though such increases might be necessary to see a program transition from its development phase to its operations phase; rather the agency's budgetary profile must be relatively constant over time. This suggests that as one project starts to consume more resources, the necessary funding will have to come from other projects. This funding will invariably come from those projects that do not have strong supporters defending them. This is particularly problematic within an agency like NASA where operations costs have traditionally been high, stifling new development. Indeed, it is more likely that a political actor will defend a program that is already operating than one that is still in its conceptual or development phase, and therefore delivering no concrete results to a constituent base. Most importantly, Wildavsky's empirically-derived observation links political events to budgetary salience, suggesting that without a clear goal established by political mandate, no incremental agency can expect significant funding changes. On the one hand, this suggests that large development programs that do not fit within the current budget are unlikely to be funded. On the other hand, this observation reveals a sort of safety net, essentially guaranteeing that, in the absence of extenuating circumstances, the

agency is unlikely to lose its current funding level for the foreseeable future. As such, an agency's survival is a sort of existence proof that it provides a valuable contribution to society. It is only when an agency tries to increase its budget that it must justify its added value against that of its competitors.

(Davis, Dempster et al. 1966; Davis, Dempster et al. 1974) build off of Wildavsky's work by creating a mathematical description of budgetary agency allocations for each year, noting that Congress tends to follow an incremental strategy in allocating funding to agencies. In effect, they note that, in the absence of what they term "political shocks", agencies will receive approximately what they received in the previous year plus some fraction of what they requested. The motivation for this description is that Congress, lacking the attention resources to re-construct the budget from the ground up every year, must instead look at the previous budget for its guidelines and base the new budget on this data. Budgetary data from many agencies confirms the incremental hypothesis for some length of time, although incremental periods are often separated by short (one- or two-year-long) periods of non-incremental behavior. These sources provide no means of predicting these shocks, rendering their theory descriptive rather than predictive. Nonetheless, it is instructive to observe that, since the end of the Apollo program, NASA's budget and activities have become increasingly characterized as incremental in recent years, particularly as Congressional influence over NASA's budgetary process became stronger. (Jahnige 1968), written near the end of the Apollo program, describes this process in detail, observing that NASA, which had previously been impervious to Congressional oversight due to its strong presidential support and highly technical nature was now subject to an increasingly aware Congress that began to exert more control in curtailing NASA's spending activities largely through the employ of technically-capable staffers.

The Politics of Space Exploration

The effects of Congressional attention on American space policy is recounted in detail in (Johnson-Freese 2003). Noting that several members of Congress see NASA as "an entitlement or jobs program for its employees and contractors", the author concludes that costs tend to grow significantly when spent for political rather than technical purposes. This perception is strengthened by the fact that the scientific and technical nature of space activities is often viewed as arcane and beyond the grasp of the average Congress member. This, in turn, motivates a focus on other, more directly salient concerns, such as geographic distribution of jobs. Regardless of the Congress member's personal beliefs, each member is motivated to remain in his or her elected position, thus requiring that benefits be provided to constituents. (Roust 2002) elaborates on this hypothesis, demonstrating the role-based power of specific committee members on NASA allocations. Thus, in order to be politically relevant, NASA must ensure that its

money is spent in line with the political powers-that-be. As a multi-member legislature, Congress is often home to many differing and sometimes changing, opinions. In the absence of strong and sustained Presidential leadership, these opinions will come to dominate NASA's agenda, often resulting in changing requirements and redesigns, as NASA tries to adapt to serve all constituencies. Nonetheless, individual Congress-members need to maintain a reputation for responsibility, both to their constituents and to the nation. This means that, in the face of cost- and schedule- overruns, Congress members will demand accountability even if the lag in performance metrics is in part created by Congressional politics. Noting that "…incrementalism occurs when the decision-maker lacks the information and knowledge to put forward space policy goals", Johnson-Freese ties Congressional action to the work of Wildavsky, suggesting that incrementalism is a specific strategy employed by a non-technical Congress to ensure oversight of, and some measure of control over, NASA's programs. (Logsdon 1986; McCurdy 1990) both elaborate on the extent to which NASA has adopted an incremental, coalition-based strategy in its dealings with an increasingly powerful Congress. Specifically, they address the circumstances surrounding the creation of the Space Shuttle and the International Space Station, both of which resulted in designs that are suboptimal from a purely technical standpoint but are nonetheless strong sources of Congressional benefits. Nevertheless, a question remains as to their efficacy in accomplishing the goals of Presidential politics. (Johnson-Freese 2003) observes that "[a]s long as the status quo is maintained, Congress seems content to remain mostly a benign benefactor…[t]he result is that Congress is not generally able to force coherent long-term change, nor does it really want to. Instead, legislative solutions tend to be across the board budget percentage cuts or caps to which agencies adapt to as best as possible. This often means continual downsizing of programs, but not a pruning out or elimination of anyone's particular program. It also explains why NASA's programs, such as ISS today, are often over budget and behind schedule". Many of NASA's cost and schedule problems are exacerbated, if not caused, by the political environment in which it sits. For example, the Columbia Accident Investigation Report (CAIB) remarked upon a "…lack, over the past three decades, of any national mandate providing NASA a compelling mission requiring human presence in space…The result is the agency has found it necessary to gain the support of diverse constituencies. NASA has had to participate in the give and take of the normal political process in order to obtain the resources needed to carry out its programs. NASA has usually failed to receive budgetary support consistent with its ambitions. The result…is an organization straining to do too much with too little." (Gehman, Barry et al. 2003) The above analysis suggests that the CAIB's conclusions regarding the political environment in which NASA exists represent the norm rather than the deviation. We may therefore expect such behavior to continue for some time to come.

Incrementalism in the Vision for Space Exploration

The Vision for Space Exploration, presumably anticipating Congressional incrementalism, advances a relatively constant NASA budget proposal for the long-term, increasing only to adjust for expected inflation rates after FY09 (see Figure 2). Unlike the days of the Apollo program, when schedule, rather than cost, was the primary mission driver, one may expect NASA's budget to remain largely constrained within this funding envelope. Furthermore, it is not inconceivable that funding might decrease in the face of shifting priorities.

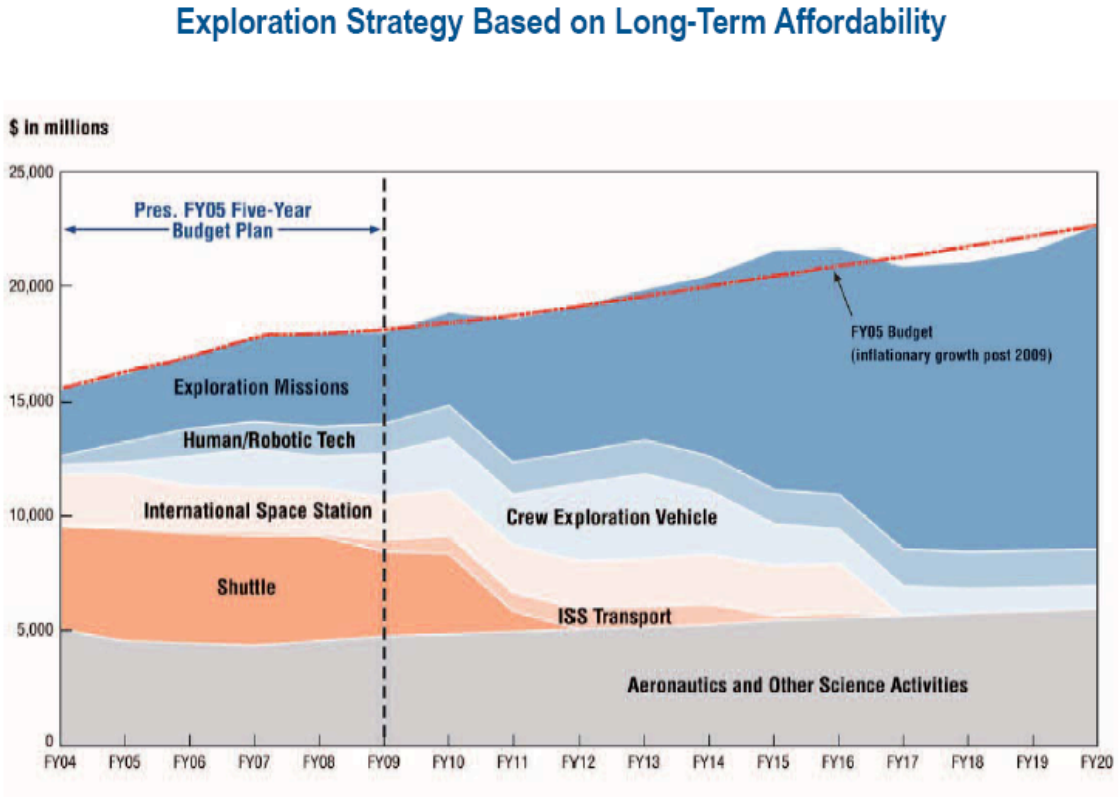

Figure 2. The following "sandchart", representing NASA's expected budget through time, shows a slight increase in NASA funding, after which the budget increases linearly in real dollars, in effect remaining constant with inflation. Source: (NASA 2004)

The linear budget predicted after FY07 is consistent with the incremental model of budgeting, which asserts that, for an agency, "models of the of the budgetary process are linear, stochastic, and strategic in character" (Davis, Dempster et al. 1966). An agency-level examination of recent NASA budgetary appropriations does indeed yield a roughly linear time-series, as shown in Figure 3. The

stochastic nature of these appropriations characterizes the slight deviations from the linear approximation. Furthermore, NASA has previously been characterized as an incremental organization following the end of the Apollo era (McCurdy 1990).

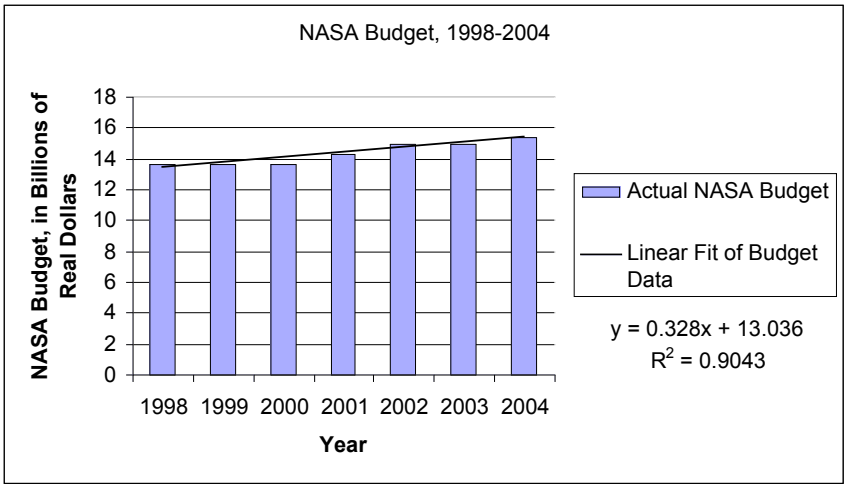

Figure 3. The above chart portrays NASA's total budget as granted by Congress, in real dollars. Note that it increases roughly linearly through time. A true incremental model would also incorporate data pertaining to the agency's budget request, perhaps providing a stronger correlation (NASA 2006).

Note that Figure 2 predicts very gradual growth through time for most of NASA's programs, with the exception that, as programs retire, their funds are folded into the Crew Exploration Vehicle and Exploration Missions. In general, this sandchart is devoid of sharp increases or decreases in funding on a yearly basis, that might belie the presence of conflict or changing priorities within the budgetary process. Nevertheless, incrementalism cannot be generalized to the programmatic level (Natchez and Bupp 1973).

Figure 4 shows the same data as in Figure 3, except that here, budget is broken down by program, rather than aggregated at the agency level.

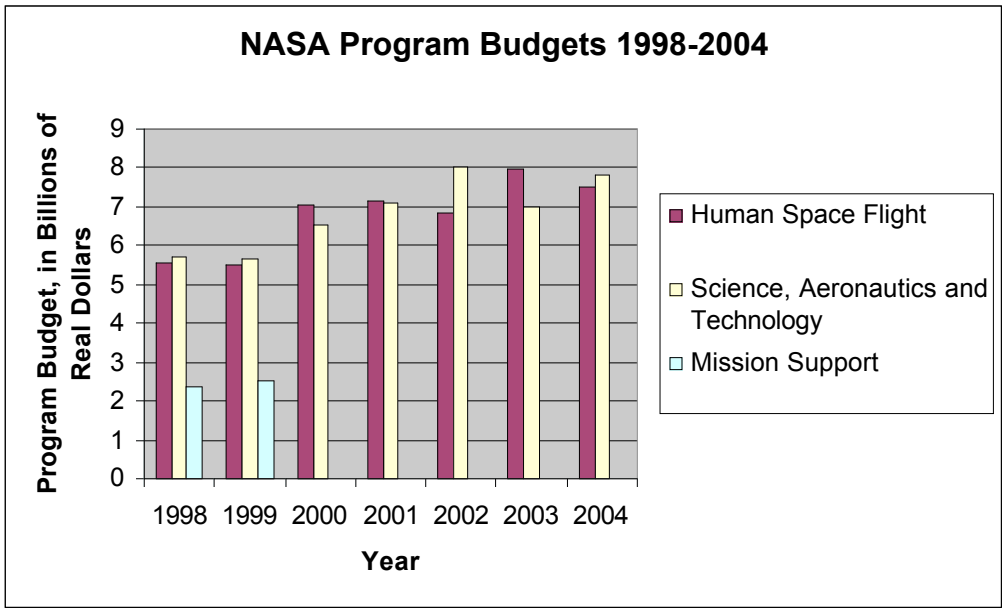

Figure 4: The above chart displays the same budgetary data as in Figure 3, broken down by program. The data are characterized by sharp, nonlinear changes associated with reorganizations (in FY2000) and shifting priorities (between FY2002 and FY2003) (NASA 2006).

Each program component historically underwent periods of non-incremental behavior. Comparing 2002 to 2003, for example, one notes a one-billion dollar shift from "Science, Aeronautics and Technology" toward "Human Space Flight". In 2004, much of this funding is restored. In addition, the year 2000 saw the folding of "Mission Support" into the other two budgetary categories. This suggests that there are political forces at work beyond the traditional budgetary "satisficing" (Lindblom 1959). Indeed, previous work has faulted the incremental model for its inability to capture such program-level dynamics. An incremental analysis is therefore insufficient to characterize the program-level budgetary environment through time. Since engineering systems are generally designed within the context of a program, rather than within the context of an entire agency, we must focus on determining the causes of these program-level dynamics.

Program-Level Politics

(Natchez and Bupp 1973) critiques the incremental model of budgeting; arguing that although the outcome of the budgetary process may indeed be incremental, the politics and the struggles leading to such an outcome are far from deterministic. Their examinations of the Atomic Energy Commission's budget

reveal that, although the agency budget possessed a relatively linear incremental profile over time, individual programs were subject to wild swings in budgetary favor that correlated with executive branch policies. Figure 4 shows a similar outcome; whereas the overall agency profile is relatively constant, the disaggregated budgets are subject to changes of up to $1 billion per year, an appreciable amount compared to the agency's overall budget of about $15 billion. This suggests that although an agency's budget is likely to be stable over time, a specific program is much more subject to unpredictable political perturbations. This is especially true if such a program is "invisible" to Congress because it lacks the backing of a powerful constituency. Without congressional support, such a program is much more likely to be used as a political bargaining chip within the Executive Branch, potentially endangering its future survival. This is particularly true if the program has neither Congressional nor Presidential salience. Lacking a powerful constituency to support it, the program is likely to be cut so as to free funding for other priorities. This, in turn, raises the question of how a program might achieve Congressional or Presidential salience, thus guaranteeing at least some measure of stability of funding.

Congress-Agency Interactions

(Cohen and Noll 1991) analyzes this problem as it relates to R&D projects within the context of the American federal system, drawing some general conclusions regarding the comparative roles of Congress and the President. Their conclusions are somewhat bleak, noting that "American political institutions introduce predictable, systematic biases into R&D programs so that, on balance, government programs will be susceptible to performance underruns and cost overruns". Nonetheless, the authors make important comments regarding how a program might achieve electoral salience, outlining three general types of circumstances. The first of these occurs when an R&D project is directly related to the state of the nation. Examples include the space race with the Soviet Union culminating in the Apollo program, the energy crisis of the 1970s leading to a brief increase in funding for alternative energy sources, and the Strategic Defense Initiative (Star Wars) missile defense system proposed during the Reagan administration. A second instance in which R&D programs become salient is the fallout resulting from a disaster or some event that exposes mismanagement or corruption within the program. Finally, the authors cite distributive effects; specifically the money and jobs created within the districts of individual members of Congress, and campaign contributions required for re-election. This particular circumstance becomes especially important when many individual constituents have a stake in the continuation of a program. The authors link political salience to contract size noting that positive spillover effects from increased employment increase salience for political representatives, eventually reaching beyond congressional districts and potentially into the attention of senators and possibly even presidential candidates. Nonetheless, as a program size continues to grow, it

will eventually reach a point of diminishing political returns. A notional diagram of this concept is show in Figure 5.

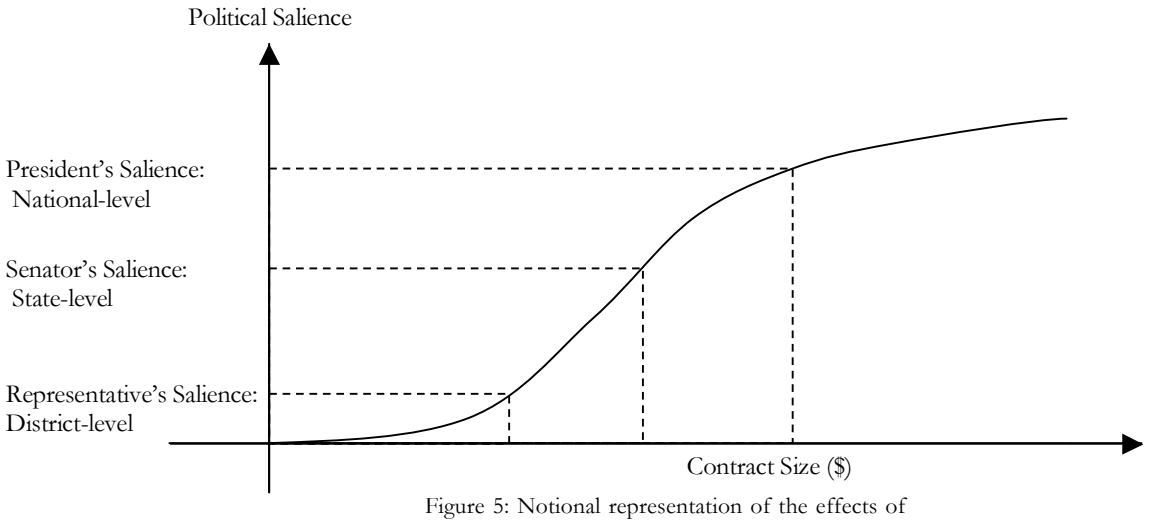

Figure 5: Notional representation of the effects of contract size on political salience

It is worth noting that a program that promises electoral advantages for the future is much less likely to receive support than a program that is currently delivering value. This is largely due to the uncertainty surrounding who will receive development contracts. Cohen and Noll note that "citizens who are unaware that they are destined to be employed in the new program are unlikely to engage in political behavior motivated by its enactment. Once contracts are awarded and workers are hired…identifiable and organized groups (firms, unions, local governments) have a clear stake." This sort of behavior, in which potential losses loom larger than potential gains, is well-documented in the risk-aversion and psychology literature, and is especially consistent with the predictions of "Prospect Theory" (Kahneman and Tversky 1979). Furthermore, we may expect Congressional representatives to share this type of behavior with regards to distributive benefits within their district, largely because their prospects for re-election depend on the continued support of their constituencies. Thus, a program is likely to engender salience from Congress members if the distributive benefits that it provides are simultaneously put under threat and sufficiently large to warrant the attention. (Cohen and Noll 1991) further elaborate on this theme, characterizing politicians, and Congress-members in particular, as impatient and risk-averse with regards to R&D programs. Since R&D programs are naturally risky prospects with uncertain results and payoffs in the long-term, they tend to

be systematically undervalued within the American political system. This suggests that programs which can deliver politically-relevant benefits early on are more likely to be sustained by Congress. The President, on the other hand, has more latitude to propose large long-term programs. Cohen and Noll note that "A president must certainly be concerned that programs initiated in one term will not be carried to conclusion in the next; however, if a program is reasonably successful, and if expenditures are large enough to cross the threshold of political significance for a number of legislators, a president can be reasonably confident that a program will be difficult to kill in subsequent sessions of the legislature." This argument casts the President in the role of proposing programs while leaving it to the Congress to sustain these programs, a statement supported by the game-theoretic analysis of (Kiewiet and McCubbins 1988). If, on the other hand, the President were to try to sustain a program unpopular with Congress, the program would likely not be successful. Therefore, the distributive goals of Congress members must be taken into account, even, and perhaps especially, with Congressional support.

The role of the agency is to ensure that the execution of a program's agenda is both politically acceptable and technically feasible. This is often accomplished through agency-industry coalitions wherein much of the agency funding is allocated to industry contractors, many of whose firms represent large political constituencies. This phenomenon, often referred to as a "revolving door" or an "iron triangle", can increase political support within Congress but has the potential to stifle innovation.

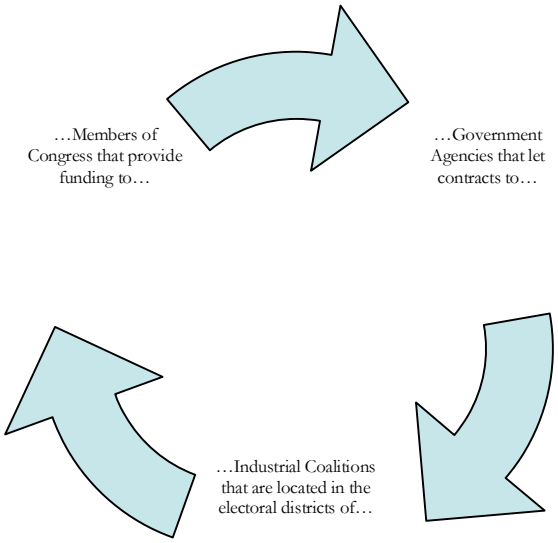

Figure 6: The "revolving door" or "iron triangle" -- a self-reinforcing feedback mechanism among

> members of Congress, Industrial Coalitions and Executive Branch Agencies (Cohen and Noll 1991).

Given the challenges inherent in generating a program that will gain and maintain Presidential and Congressional salience, (Cohen and Noll 1991) discusses many of these issues in significant detail, outlining a set of general characteristics that an R&D program might posses in order to make it more likely to survive in the political environment. These characteristics are as follows:

"First, the government is more likely to be willing to undertake programs oriented toward a concentrated industry than a competitive one." (Cohen and Noll 1991)

This particular characteristic speaks to the relative political ease of associating with a small, concentrated number of players rather than a larger, more diffuse interest (Olson 1984). For the purposes of determining the available budget for a new development program, this characteristic speaks to the Congressional desire to avoid alienating a key constituency. Thus, the concerns of those groups that are heavily invested in aerospace must be taken into consideration. For example, this characteristic suggests an advantage to using legacy components for NASA's CEV design, if only to maintain the support of the producers of those components.

"Second, R&D projects will be more attractive if they address a broadly salient national political issue, so that they plausibly constitute an effective response to a concern of the citizenry at large." (Cohen and Noll 1991)

This characteristic is driven by the Congressional requirement that a coalition be built in order to achieve action. Although each member of Congress serves a given fixed constituency, a program is much more likely to receive support from fellow members if it is viewed as a boon to the nation, rather than simply a "pork-barrel" for particular districts. It is within this context that the national pride and prestige elements of human spaceflight become the most important – if a majority in Congress perceives that the national interest is threatened, more support may be expected. The Apollo program was the archetype of this modality (Van Dyke 1964). Nevertheless, such threats are generally short-term in nature and cannot be expected to provide sustainable results. NASA Administrator Griffin's drive to accelerate the CEV represents such a concern, ensuring that the US will not cede superiority in human spaceflight to other nations (Technology News 2005).

"Third, an R&D program will be more attractive if it has a short time horizon and does not entail a radical change in the technological base of an industry." (Cohen and Noll 1991)

This characteristic speaks to the need for Congress members to show results to their constituents within an election cycle (as little as two years for a US representative). Furthermore, the industrial base requirement suggests that the costs of showing these results should be relatively small and should displace the smallest number of people and equipment possible. In the specific context of the CEV, this characteristic provides a direct justification for acceleration of the program while simultaneously maintaining the employment of the existing aerospace workforce. Once again, legacy technologies are useful in implementing this directive.

"Fourth, the net benefits of a program are likely to play an important role early in the history of a program, simply because there are only weak political reasons to undertake a program unless it is economically attractive." (Cohen and Noll 1991)

The explanation for this characteristic is similar to that of the previous two. When a program is first proposed, it requires a broad national consensus in order for it to be approved and then funded. In order for it to avoid cancellation, it must deliver upon these commitments. Nevertheless, once the program has become significantly entrenched, individual members of Congress will be willing to expend political capital to advocate for its continued existence. This is largely because it is in their interest to see to their constituents' continued well-being. There are also valid national reasons to maintain a skilled workforce that can be mobilized when necessary, but until such a mobilization is required, the benefits of this maintenance are conferred upon those particular regions of the nation where the workforce is located, whereas the costs are diffused upon the entire nation. Programs often take advantage of this characteristic, using what is euphemistically referred to as the "camel's nose": An agency may "wedge" a program into the budget, initially requesting little and then allowing costs to overrun as the program matures (Wildavsky 1964).

"Fifth, programs that can be fragmented into many, largely independent components are usually more attractive politically than programs that can be implemented only if they are centralized." (Cohen and Noll 1991)

The logic underlying this characteristic relates to the observation that support in Congress is roughly proportional to the number of Congress members willing to advocate for the program (exceptions to this rule involve the support or opposition of powerful figures such as chairs of relevant committees, and other

leadership positions). If a significant number of people are employed by a given program within a given district, the representatives of that district will be willing to lend their political capital to the cause. A technical system that can be easily fragmented and spread around the country such that parts of it can be built in many districts will benefit from this support (Klein 2000). Distributed management brings similar benefits (Baldwin and Clark 1997). For example, the Space Shuttle program gained significant support from the Utah delegation in Congress when Morton Thiokol, a Utah-based company, was selected as the prime contractor for the Shuttle's Solid Rocket Motors, even though this required that special additional infrastructure be created to transport these often highly volatile components to Florida for launch (Hoff 1997). The Space Shuttle and International Space Station programs have been highly successful in maintaining Congressional support through distribution. Thus, this characteristic suggests that the distribution assigned during these programs not be changed, and that existing infrastructure be utilized to the greatest extent possible. It is generally considered politically prudent to locate these facilities (and the resulting jobs) in the districts of powerful members of Congress. Nevertheless, it is not advisable to spread the program too much. Given that NASA's budget is relatively fixed and incremental, over-spreading of the program will lead to less spending per district, engendering less support from each Congress-member. In all, the distributive benefits to be realized would be too small to cross the threshold of political salience (Kingdon 2003). Furthermore, members of Congress will usually not advocate to increase the number of jobs in their district – rather, they will simply defend the employment of those already there (Cohen and Noll 1991). In addition, transportation and communication costs engender technical inefficiency.

Figure 7 displays the distributive breakdown of the Space Shuttle program.

Figure 7: Locations of Space Shuttle contractors and suppliers. Imagery obtained using Google Earth (http://earth.google.com). Data obtained from (Dumoulin 1988).

A plurality of Space Shuttle contracts are located in southern California, generally considered to be the seat of the American aerospace industry. There are also other large constituencies that must be taken into account, including the Kennedy and Johnson Space Centers (in Cape Canaveral, Florida and Houston, Texas, respectively), Lockheed Martin's Michoud Shuttle External Tank Assembly Facility in Louisiana, and ATK's Solid Rocket Booster plant in Brigham City, Utah. These regions represent powerful constituencies as well as a high concentration of skilled aerospace workers, and are natural considerations for legacy design. Re-use of the facilities and components mentioned above therefore has significant political, as well as technical and economic, benefits. It should be explicitly noted that the political benefits that accrue are only in effect for as long as the actual legacy systems are still available. For example, a choice to use the Saturn V rocket within the space exploration architecture would likely be unsupportable, if only because no Saturn V has been built in over 30 years – the infrastructure required to do this no longer exists. Similarly, the Apollo TPS (thermal protection system) material, Avcoat 5026, is no longer in production, leaving NASA without a replacement human-rated ablative TPS material (The Charles Stark Draper Laboratory Inc. 2005).

"Sixth…Proponents of unattractive ongoing projects…will often seek logrolls with advocates of new programs, thereby achieving majority support and presidential consent for the entire package." (Cohen and Noll 1991)

This characteristic speaks to the practice of Congressional "logrolling", wherein one member will support another's agenda in return for a future vote of support. Linking new programs to old programs allows the implied continuation of one program by folding it into another. In other words, transitions between programs should be sufficiently smooth that the end of one program is indistinguishable from the start of the next (Wildavsky 1964). Use of legacy components on the CEV enables supporters of the Shuttle and ISS programs to claim a linkage to a popular Moon/Mars exploration endeavor. At the same time, proponents of this new exploration program can point to the Shuttle and ISS programs as stepping stones to their goals. This characteristic therefore acts to minimize technical change from year to year. Agencies take advantage of this characteristic through the "bundling" of programs: If an agency's budget is to be cut, agencies may try to cut the most popular program using a deterrent threat as a political maneuver (Wildavsky 1964). On the other hand, if cuts are certain, losing the least popular programs will maintain a coalition (Wildavsky 1964). Thus, the political calculus of a program manager within an incremental agency depends strongly on how much support s/he expects the program to receive. It is for this reasons that agencies maintain strong ties to Congress through liaison offices (Murphy 1972).

One may conclude from the above characteristics that the average incremental Congress will base its decisions largely upon considerations of cost, schedule, performance, distributive benefits, and national utility. In particular, we may distinguish two modes of behavior under which a program might receive support. The first mode, characterizing the Space Shuttle and International Space Station programs, is best described as incremental. Under this regime, cost, and to a lesser extent, schedule, are the main architectural drivers of the program (Maier and Rechtin 2000). Without a clear national goal to adhere to, Congressional support for these programs focuses on the distributive benefits that they may deliver to individual districts (Kingdon 2003). Coalitions are built around maintaining these entrenched interests, sometimes at the expense of technical performance metrics (Cohen and Noll 1991). The second mode, characterizing the Apollo program and other pride and prestige items, is much more performance-driven (Van Dyke 1964). Although distributive interests do play a large role in the structuring of the program, the need to achieve high performance mitigates the resulting inefficiencies somewhat (McDougall 1985). The presence of a national goal or national concern helps to focus efforts and can serve to draw resources to the program, mitigating the budgetary wrangling often associated with incremental programs. Nevertheless, the nature of national crises is that they must generally be solved quickly. Thus, this latter mode is likely not sustainable

over a period of time sufficiently long to execute the entire Vision for Space Exploration or any other sustained directive. Furthermore, national goals are subject to rapid change and are motivated by such things as economic prosperity and foreign threats, most of which are rapidly changing and notoriously difficult to predict. The checks and balances system of the US federal government is configured to establish oversight by the Congress of large, Presidential expenditures. Therefore, even in the presence of a long-term goal, one may expect the eventual *modus operandi* of federal agency spending to be incremental and distributive. This pattern is confirmed by NASA history (Jahnige 1968). Thus, we may think of the budgeting process for NASA as consisting of an incremental steady-state with occasional transient peaks. As such, we may expect Congressional valuations of NASA's budgetary request to be different during these peaks as compared to the incremental steady-state. Table 1 summarizes the type of behavior that we might expect from Congress, given the environment in which a budgetary request is made:

Table 1: Expected Congressional budgeting behavior under periods of incrementalism and national salience

Incrementalism	National Salience
Slight changes in budgetary allocation from year-to-year	Infrequent larger changes in budget are possible
Program is cost-driven – budget-constraints drive design and outcome.	Program is schedule- and performance-driven – budget is negotiable to meet objective.
Coalition-building drives re-use of legacy components – sometimes at the cost of technical efficiency	Drive toward technical optimality allows development of new components and facilities.

The above analysis demonstrates that policy choices do not stand in a vacuum. Rather, they may be influenced by many factors, including technical choice. Space systems, and space system engineering, are complex by nature. That complexity is exacerbated by uncertainty within the political environment. Although some work has been performed enumerating the effects of policy choices on the technical architecture, there is no clear framework for how technology affects policy. This thesis is aimed at providing such a framework within the context of NASA's space exploration plans.

Conclusion

The political science literature provides us a sense for what motivates political change. Whereas technical choice is based upon tractable theory that can be

pursued to a rational and often deterministic end, political choice is marked by an environment of information scarcity wherein many of the options available to a decision-maker are not clear. A political decision-maker is thus forced to choose between a limited number of generally sub-optimal options, often without the time or ability to investigate the full ramifications of these options in detail. As such, an entity that can exercise control over the information available to policy makers can exercise some element of control over the outcomes. In particular, NASA's technical expertise allows a powerful role in defining options that are to be presented as policy choices.

It is up to the policy maker to make decisions based upon what information and options are the most salient to his/her own values. To the policy-maker, agencies, such as NASA, are tools to be used in implementing a specific policy directive. Therefore, an agency will receive attention when its work can be used to satisfy a salient directive, or when its goals are instrumental towards achieving the policy-maker's goals. Since goals change, an agency cannot always fulfill a salient concern. During these periods, they are dominated by role-based activity. The budgeting process, in particular, is dominated by a particular type of role-based activity often referred to as "incrementalism". Furthermore, there is a considerable body of space policy literature characterizing NASA as incremental. As such we can expect NASA's budgeting behavior to be largely driven by the same forces that drive most incremental agencies. Generally, these act to maintain the status quo by creating an environment of budgetary scarcity for new projects. In technical terms, this drives the agency to reduce costs of new programs. Use of legacy components and technology is one widely-used means of reducing costs while simultaneously forging a political linkage between new and old programs.

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