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Human Spaceflight Decision-making As A Potential Well Problem

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HUMAN SPACEFLIGHT POLICY DECISION-MAKING AS A POTENTIAL WELL PROBLEM

by

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ABSTRACT

This study investigates funding within the US human spaceflight program in the time-period from 2004 to 2012. The approach taken employed the "potential well" model from physical science. The potential well model constrains any physical body trapped within it, and similarly a political "funding well" will constrain all programmatic decision-making.

Two potential well models are employed, one represents classical physics while the other represents quantum physics. Since each model results in motion with certain properties, it can be seen if funding decisions also exhibit similar properties. In physics, the bifurcation between the classical world of aggregate bodies and the quantum world of individual particles is an indicator of deeper physical principles. This study seeks to explore whether this bifurcation exists in the political world as well. If so, it would help explain space policy evolution from 2004 to 2012, and provide evidence concerning the usefulness of physical models for discovering further trends in social science, including political science.

The study of a bifurcation in space policy political decision-making resulted in an unclear relationship since some properties were found to be similar to their physical counterpart, some were found to be different, and one property, the quantization of funding into discrete increments, was absent from political decision-making. Further studies are required to explore this bifurcation in greater detail. However, the potential well did prove to be a powerful model in explaining the evolution of human spaceflight policy in 2004 to 2012 as it provided a framework to explain dynamics that may have otherwise remained unclear.

Dedicated to my family and friends.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

CBO	Congressional Budget Office
CCDev	Commercial Crew Development
COTS	Commercial Orbital Transportation Services
CRS	Congressional Research Service
GAO	Government Accountability Office
ISS	International Space Station
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
QDT	Quantum Decision Theory
SLS	Space Launch System
VSE	Vision for Space Exploration

CHAPTER ONE: INTRODUCTION

Decision-making in political science may have mechanical analogues in the physical world, and comparison to these physical analogues could produce a deeper understanding of the decision-making process. In much of political decision-making, and in human spaceflight policy specifically, the decision-making process is bound by the cost, in financial terms, of programs. An analogy will thus be drawn between budgeting in politics and energy in physics, concepts with similar functions.

Specifically, budgetary decision-making will be modeled using the concept of the potential well which is a region in space whose borders exert a force which traps a particle or physical entity within the well. Both classical and quantum potential wells will be described, with the purpose of noting which one more closely models decision-making processes.

The political question at stake is one drawn from human spaceflight policy. The period from 2004 to 2012 saw a great change in the US civil space program. Human spaceflight and its attendant cargo component are moving from near complete reliance on the National Aeronautics and Space Administration (NASA) to a partnership between NASA and a growing private space launch and operations sector. Why is this evolution occurring, and why at this time? It is likely that budgetary concerns are the primary cause of this change. Space operations and programs, especially human spaceflight, are expensive and cost predictions contain a great deal of uncertainty and this state of affairs impacts decision-making.

In the remainder of this introductory chapter, the study's outline will be developed. Its thesis will be discussed, followed by a literature review of political decision-making in human spaceflight policy. As a multidisciplinary study, a literature review for two different fields is required: space policy and physics-based energy models as a methodology. Finally, the research design will be discussed. Unlike previous studies of political decision-making, the focus on funding and application of the potential well model from physics provide a fresh view.

Thesis and Hypothesis

This study stems from the assumption that the dynamics behind human decision-making can exhibit qualities that are similar to the physics of both classical and quantum systems. In physics, quantum mechanics provides an explanation for the movement of subatomic particles, and the properties of quantum systems stem from the fact that particles are not concrete entities, but instead are governed by probabilistic functions. In other words, a "particle" is as much a wave and not located in a single place, with the best description as a probabilistic function noting the chance for a particle to be located somewhere. When particles come together to build the large-scale physical bodies of the macroscopic world however, their interactions with each other constrain their wave nature and thus large bodies follow deterministic rules. They have definite positions and velocities which can be measured.

A similar framework may explain human decision-making. Individual human beings, like particles, make decisions based on probabilistic information. When a policymaker chooses to support or reject a policy, he or she has a particular goal in mind and utilizes experience, history, ideology and other mental tools to make the choice that will best reach the goal. People cannot predict the future with certainty; however they do try to make decisions based on best chances, a situation that exhibits quantum properties. While any given individual will make decisions based on a wide range of choices, when in groups and exhibiting organizational decision-making, the choices of many people tend to constrain any given single individual. Norms, standard operating procedures, laws, and other organizational frameworks create a body whose decision-making is constrained and closer in nature to classical physics.

It is expected that individual decision-makers will exhibit quantum properties while large organizational decision-makers will exhibit classical properties. The focus in this study is on budgetary decision-making and a key question consists of what both quantum and classical budgetary decision-making would look like.

This study focuses on human spaceflight decision-making in the period from 2004 until 2012. The early part of this period is associated with the George W. Bush Administration's Vision for Space Exploration (VSE) announced in January 2004. This program was meant to be a return of US astronauts to the moon, as a larger version of the 1960s Apollo program, and operated nearly completely by NASA in a manner similar to earlier US space efforts yet it proved too expensive. The second part of the period is characterized by the Obama Administration's cancellation of the VSE program and shift to a focus on private enterprise to work together with NASA in human spaceflight operations. The key concern is identifying what led to the decision to make this particular evolution in US human spaceflight.

“Money is the mother's milk of politics,” according to Jesse M. Unruh, the 54th Speaker of the California State Assembly. It is with this wisdom in mind that budgetary funding becomes the primary concern for decision-making in human spaceflight policy. This study utilizes the potential well model to explore budgetary decision-making, and in physics, energy is required for bodies to undergo motion. Similarly, political motion or change is made possible through the power of money.

The potential well is simply an area of space in which potential energy creates a force that binds a physical entity, allowing it only constrained motion. Analogously, a “funding well” can trap a policy initiative allowing it to evolve in only a constrained way (essentially limiting the choices a decision-maker has in changing or continuing a policy). In classical physics, the physical body is trapped unless additional energy is added to the system from outside. In quantum physics, a particle's motion being a probabilistic function, makes it possible for the particle to leave the well without the required extra energy. Additionally, due to these probabilistic effects, the particle is highly constrained as to what states it will be found in. The mechanics of these models will be explained in greater detail later, however, they may be analogous to different political situations. It is hypothesized that classical physical bodies which are made up of aggregates of particles may mirror the workings of organizations, while the quantum realm of individual particles best models individual decision-making.

Thus, this raises a handful of questions: First, the question of why the change from a mostly government run space program to one much more reliant on the private sector can be explained in terms of motion in the potential well. Next, does the potential well serve as a good model for political decision-making, and is there a bifurcation between individual and organizational decision-making analogous to the particle-aggregate body split in physics? To answer these questions, funding decisions that lead up to the change in space policy in 2009-2010 will be analyzed to see if they act as decision-making equivalents of bodies in potential wells. Motion in a potential well has unique properties depending on whether it is classical or quantum. These properties will be discussed later and it will be seen if they adequately describe human spaceflight policy decisions. Then each set of decisions, the more classical in nature and the more quantum in nature, will be analyzed to see which decisions were championed by individuals and which by organizations. It is hypothesized that individual decisions will be quantum in nature, while organizational decisions will be classical. If this is true, then the study shows that physical and political phenomena have at least this fairly deep similarity, and that other physical models may be able to help with further understanding of political decision-making.

Significance of the Topic

The significance of this study lies in that it provides both an explanation for a particular set of decisions in human spaceflight policy, why the evolution to a deeper public-private cooperative effort occurred in the 2004-2012 time-frame, as well as makes the case that physics models can be useful in studying social science topics.

The focus on human spaceflight decision-makers and stakeholders represents bureaucratic politics, with a focus on organizations. For the US human spaceflight program, the key stakeholders are the president, Congress, the National Aeronautics and Space Administration (NASA), and the public (Broniatowski and Weigel 2008, 148). Pertinent corporations and organizations in the business community can be considered another stakeholder, with growing public influence, yet still weak compared to the others.

How this bureaucratic level links to the international or state level is a significant consideration. For projects such as the International Space Station (ISS), stakeholders include the bureaucracies of other partner states, and funding and support is reliant on cooperation. This study can help shed light on international processes where the states under consideration are not simply black boxes. Halperin, Clapp, and Kanter discuss the evolution of the bureaucratic approach toward the importance of explaining how internal and individual processes lead to state behavior (Halperin, Clapp, and Kanter 2006, 243).

This study also seeks to add to the field of quantum decision theory (QDT) by use of potential well models that utilize both classical physical and quantum physical varieties. QDT is a relatively new field whose basic principles are still under development. The potential well model represents a next step in the development of this methodology, and the application of quantum decision theory to fields within political science represents an expansion of its usefulness. While this study presents a more qualitative look at decision-making, it is hoped that this first effort can assist in leading to a more mathematically rigorous quantitative model. This goal is part and parcel of the need in the social sciences for continued methodological growth.

It is hoped that the use of quantum decision theory helps lead to what Rein Taagepera calls “interlocking”, a phenomenon in the natural sciences in which a network of interrelated equations exists (Taagepera 2008, 66). In physics, both interconnectivity and parsimony matter, and even in political science, which struggles with both, they are held in high regard. Also in physics, the use of reasoning that follows logical sequential patterns and has been pared by Occam's Razor (meaning that it explains in the most simple terms available) has led to amazing breakthroughs (Taagepera 2008, 68). This study seeks to demonstrate that similar reasoning can produce similar results in political science.

In terms of its theoretical basis, this study is predicated on the belief that the physical world is the basis for the social world. Ultimately, social rules are based on underlying physical rules, and social scientists can gain much from understanding how the former are derived from the latter.

<u>The Literature Review and the Topic in the Literature</u>

This study consists of a combination of three literatures: space policy, bureaucratic politics, and physical science and quantum decision theory. Each of these fields is at a different level of development with its own distinct traditions, and bringing them together poses a challenge. However, doing so also offers the opportunity of a synthesis that is greater than the sum of its parts.

The space policy literature goes back over the fifty years for which space programs have existed. Its early history is linked to Cold War politics and nuclear strategy, yet US human spaceflight is conducted through a civilian organization, the National Aeronautics and Space Administration (NASA). The space policy literature is a fairly disorganized field, comprising many contributors from both the academic and policy spheres, with no seminal scholars or works whatsoever.

Even so, this study makes use of the material in this sub-field that is concerned directly with decision-making during the 2004-2012 time-frame. Erik Seedhouse gives an excellent overview of the Constellation program and the politics that went into its development up to 2009. Roger D. Launius and Howard E. McCurdy discuss the myth of the US president's support as the driver of a successful human spaceflight policy, which has been around since President John F. Kennedy's support of the Apollo program. David A. Broniatowski and Annalisa L. Weigel discuss the role of congress as responsible for deciding on the level of funding a space program receives, and what that body considers in making such decisions.

Due to the time-frame under study being very recent and up to the present day, more timely news sources and internet websites provided an excellent source of information. First and foremost, NASA itself keeps an extensive archive on its website covering Constellation and commercial enterprise in space. Marcia S. Smith has authored numerous articles for the Congressional Research Service (CRS) and is the webmaster for the website SpacePolicyOnline.com which is primarily concerned with congressional issues in space policy. This site, as well as the Government Accountability Office and the Augustine Report, provided budgetary data. Finally, many news articles from reputable agencies provided budgetary numbers as well as information on political decisions and changes in the human spaceflight program.

The bureaucratic politics literature, like that of space policy, goes back decades. For this study, bureaucratic politics was used as a framework to understand the decision-making tendencies of organizations. A foundation was provided by Graham Allison's *Essence of Decision* (1971, with a second edition in 1999 with Philip Zelikow), a key seminal work that contains the bureaucratic “organizational behavior” and “governmental politics” models. Allison was the first to note the concept of “pulling and hauling” in bureaucratic politics. This may account for the forces of constraint within organizations that, like bonds between particles which cause aggregate bodies to follow classical physical laws, allow groups of people to act in a more classical fashion. An edited work by Morton H. Halperin, Priscilla A. Clapp, and Arnold Kanter in 2006 provided further framework by expanding on bureaucratic politics and its link to state behavior. The work is a thorough current overview of the sub-field from the foreign policy perspective, to which the study of bureaucratic politics is tightly linked.

However, Allison was not the first scholar of bureaucracy. Robert J. Art notes two distinct "waves" in the early tradition of the field and lists Roger Hilsman, Samuel Huntington, Richard Neustadt, and Warner Schilling as first wave scholars and Allison as the beginning of a second wave (Art 1973, 468, 472). The first wave was active in the 1960s and focused on process in decision-making, while the second wave of the 1970s focused on organizational position. The immediate post-Allison scholars, Robert J. Art, Jerel A. Rosati, Morton H. Halperin, and Stephen D. Krasner are all second wave theorists. In the 1980s a third wave began, focused on the bureaucratic institution and delegation to bureaucracy by politicians and marked by empirical analysis and the use of formal modeling (Huber and Shipan 2006, 257). This study seeks to expand on the formal modeling trend in bureaucratic politics, by utilizing models from physical science to explore organizational behavior.

The 1980s also saw development of new theories of the policy process. Three that have added to the field are John Kingdon's "Policy Streams" approach, Paul A. Sabatier's "Advocacy Coalition" approach, and Elinor Ostrom's "Rational Actors Within Institutions" approach. Kingdon's theory relies on the interplay between three "streams": the problem stream, policy stream, and political stream. The theory makes a distinct split between those who gather information about a problem, those who analyze a problem, and those who hold office to create policy solutions. Sabatier's framework notes policy change as being dependent on advocacy coalitions of many public and private stakeholders at various levels of government as well as other policy sub-systems and institutions. Finally, Ostrom's model holds the individual as the basic unit and based on attributes of both the individual and the decision situation (Sabatier

1991).

This study certainly pulls from Kingdon's and Sabatier's approaches, in terms of the concern of space policy development across many actors (President, Congress, NASA, private enterprise), and in terms of the links between policy decisions and various decision-makers. Ostrom's work, most of all, provides an excellent foundation for this study. Her focus on the decision situation as well as the individual is the basis for the inclusion of the quantum-based model. This study, then, is an attempt to take the policy decision-centered approach and utilize models from physical science to explore it in greater detail. Furthermore, this study continues a tradition of utilizing analogical reasoning, a common tactic in both policy process study as well as political science as a whole.

To illustrate the potential well models, works from physical science are needed. L. D. Landau and E. M. Lifshitz cover both the classical and quantum potential well models, however their work is written as a reference for an expert in the field. Further material was needed to fully describe these models. For the classical model, Jerry B. Marion and Stephen T. Thornton provide a clear description and explain how the classical well leads to oscillatory motion.

For the quantum potential well, David Bohm, R. Shankar, and David J. Griffiths all provide excellent descriptions. Bohm covers the concept of quantum tunneling in detail, while Griffiths provides an explanation of the importance of probabilistic motion in quantum mechanics. Shankar gives an excellent overview of the model.

Research Design

Research design encompasses both the organization of this study as well as an explanation of the methodology which will be employed.

Organizational Design

This study consists of four chapters in addition to this introductory chapter. The first details the potential well model in both its classical and quantum varieties and how this model relates to decision-making. The following chapter details human spaceflight policy from 2004 to 2012 and the changes that took place during that time-frame, including the measurement of funding during this period. Next, a chapter looks at decision-making in human spaceflight policy as a potential well problem. Three questions are proposed: Is decision-making in human spaceflight a potential well problem? Is decision-making in human spaceflight classical or quantum in nature? Why did the US human spaceflight program evolve as it did from 2004 to 2012? It is hoped that in answering these questions the analogy of the potential well can shed light on a deeper understanding of the political decision-making behind the evolution in human spaceflight policy in the period from 2004 to 2012. The chapter ends with considerations for linking this study to decision-making in a more general sense. Finally, the last chapter concludes the study with a discussion of analysis results, problems with the research, and subjects for future development.

Methodology – The Potential Well Model

The potential well model comes from physics and can be used as an analogy for decision-making in human spaceflight policy. A potential well is an area of space which traps physical bodies due to the force of potential energy. Physical entities within a potential well exhibit different behavior depending on whether they are within the realm of classical physics, or quantum in nature.

The classical potential well is a fairly simple model in which a physical body is trapped within the well unless it has the energy required to escape. A good example is a gravity well, such as that created by the Earth. Human beings are trapped within the Earth's gravity well unless they can muster the energy required to leave the planet. This example is well understood by those in the field of human spaceflight. In terms of the motion of a physical entity trapped in a potential well, we can expect it to be anywhere within the well that its own energy level allows it to be and to only be able to escape the well if energy is transferred to it from an outside source.

In a quantum potential well, the motion of a trapped particle is very different from the classical model. The reason for this difference comes from the probabilistic nature of particles and quantum effects. Particles are not simply small localized bodies with a definite position and velocity (whereas this satisfactorily describes classical physical bodies). Particles exhibit the effects of the Heisenberg Uncertainly Principle in that their position and momentum cannot be measured at the same time. What are termed particles in quantum mechanics are sub-atomic, and are as much waves, thus we can only expect to “find” them based on their probabilistic wave-function. The ultimate ramifications of this are that particles can only be at specific quantized energy levels within a potential well—they cannot simply be anywhere within the well—and that they can exhibit quantum tunneling effects, escaping the well yet without attaining the energy needed to do so in a classical sense.

To apply the potential well model to human spaceflight policy decision-making, the various parts of the model must be defined in political science terms. The particle or physical body trapped within a potential well becomes a policy choice trapped within a funding well. The policy requires a certain level of funding to be put into action. The well represents the critical budgetary level it must reach, and can best be thought of as the level required for a particular program to be successful. The height of the well is the level of energy (the whole space budget) and its width represents the size of the pool of possible policy choices available to a decision-maker.

This model can shed light on whether a distinction exists between the classical and quantum levels in political decision-making. In physics, the quantum mechanical world is that of the very tiny individual particles and their probabilistic nature, while the classical world is that of aggregate bodies and their deterministic nature. Is the political world similarly split between individual decision-makers who exhibit quantum tendencies and organizational decision-making which may be more classical in nature. Can the analogy between human spaceflight decision-making and the potential well model discover such a relationship? If so, we can learn, through the understanding of the physics behind quantum systems, how probabilistic human decision-making leads to aggregate events.

CHAPTER TWO: DECISION-MAKING AND THE POTENTIAL WELL MODEL

Classical and Quantum Decision-making

This chapter describes the potential well model which will be used to explore budgetary decision-making. While the model itself will be explained later, it should first be made clear how the model will assist in explaining decision-making.

The key assumption in this study is that a bifurcation exists in political decision-making (and in fact decision-making in general) between quantum individuals and classical organizations, similar to physics. To test this assumption, decision-making will be explored using both classical and quantum potential well models. Due to the differences between quantum bodies or particles with a probabilistic nature, and aggregate bodies which are more deterministic, the outcome of motion in the potential well leads to different properties. Classical bodies tend to exhibit oscillatory motion and the need for greater energy than that of the well height to escape, while quantum particles exhibit quantization of their energy levels and the capability to tunnel through the well walls to escape.

These differences allow for a structured exploration into the nature of decision-making. Decisions will be tested for each of these properties as well as linked to the nature of the decision-maker. It is believed that organizational decision-makers will make choices that exhibit the properties of motion in a classical potential well, while individual decision-makers will exhibit the properties of motion in a quantum potential well. If this hypothesis is accurate, this study will have made a case for the classical-quantum bifurcation being applicable to the social as well as physical realm. The argument will have then been made for further exploration into utilization of physics methodology in the social sciences.

The Potential Well Model

The potential well model, also known as the “particle-in-a-box” comes from physics. It consists of an area in space in which potential energy creates a force that binds a physical entity, allowing it only constrained motion. In classical physics, the physical body is trapped unless additional energy is added to the system from outside. However, in quantum physics, a particle's motion is a probabilistic function, and due to this it is possible for the particle to leave the well without the required extra energy.

In politics, budgetary funding is analogous to physical energy as it provides the means by which political motion (decision-making) is accomplished. As claimed above, just as in physics there is a classical model which deals with aggregate physical bodies and a quantum model dealing with individual particles, the political world can be similarly divided. Individual decision-makers are motivated by their own imperfect knowledge about the world as well as their deeper psychological makeup, while organizations are subject to constraint due to what Allison calls the “pulling and hauling” of bureaucratic politics (Allison 1999, 255) in the same way that physical bonds between particles cause aggregate bodies to follow the laws of classical physics. Thus, it is hypothesized that individual human decision-makers will exhibit probabilistic quantum properties, while organizational decision-makers will exhibit those of the aggregate classical bodies.

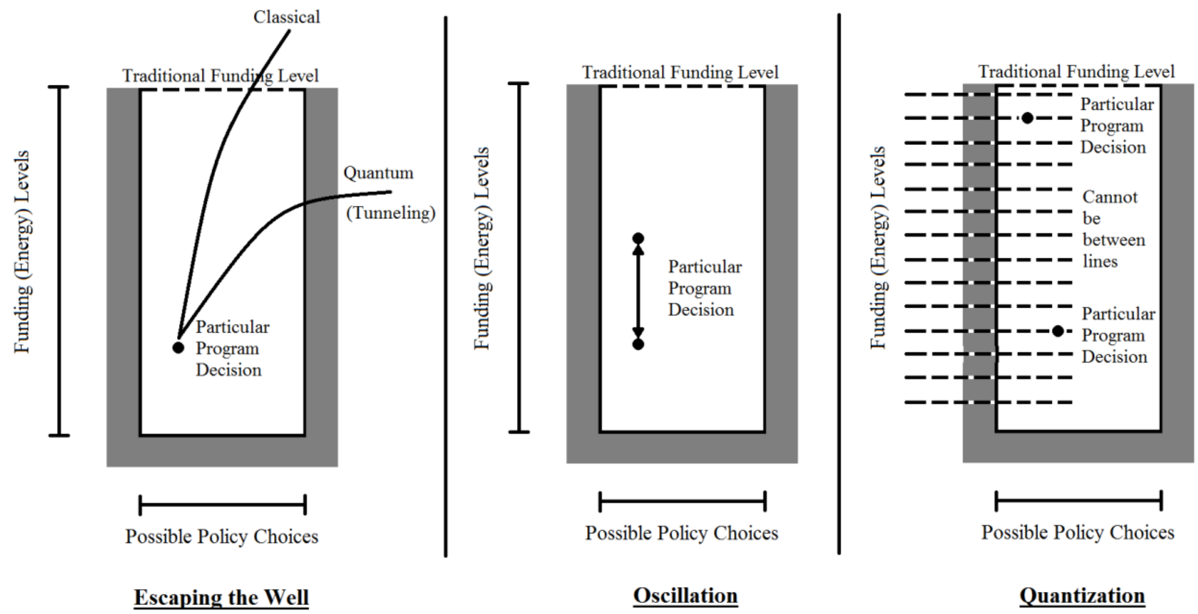

Figure 1: Potential Wells and Their Properties

In its physical sense, the potential well itself represents an energy barrier. In politics, funding is analogous to energy and the barrier can be thought of as a funding well. A given policy requires a certain level of funding to be put into action. The well represents the critical budgetary level it must reach. The height of the well is the level of energy that must be overcome, in this case the US space budget, and its width represents the size of the pool of possible policy choices available to a decision-maker. This chapter will discuss each model, classical and quantum, in its physical sense and how each translates to political decision-making.

The Classical Potential Well

The classical potential well is a relatively simple concept and can best be understood with illustrative examples. On a large scale, the Earth itself is a gravitational potential well. Humans and animals are trapped on its surface, or in the case of flying animals, fairly close to the surface. Their motion is constrained to this area. However, with the energy from rocket fuel, humans can escape the Earth's gravitational pull into space.

Or on a much smaller scale, imagine a half-pipe with a skateboarder rolling back-and-forth between the high points. For the skateboarder to leave the half-pipe he would either have to enter with enough energy to escape on the other side, or energy would have to be added from an outside source (say someone pushing him up and out of the half-pipe). Otherwise, the skateboarder will be trapped within the pipe, only able to move back and forth. These examples both show that to escape from a classical potential well simply requires the physical body to have more energy then that of the well itself. Without the required energy, the body is trapped within the well.

So what does the physics tell us about the classical potential well? Landau and Lifshitz give a derivation of the case in which the bounds of the well are areas where the potential energy equals the total energy of the system. Potential energy is stored by a system, while kinetic energy—which together make up the total energy of a system—is that which is in use and allows for motion to occur. Thus at these points, there is only potential energy in the system, and so velocity is zero, causing oscillatory motion for any body traveling in this space (1960, 25-27). This would be the case for a pendulum swinging back and forth, constrained from moving in any other fashion by its attached string. Marion and Thornton give their own explanation of oscillatory motion caused by the constraint of a potential well (1995, 155-159). They also note when the concept of potential is useful stating,

> “We should not... lose sight of the fact that the ultimate justification for using a potential is to provide a convenient means of calculating the force on a body (or the energy for the body in the field)-for it is... not the potential that is the physically meaningful quantity (Marion and Thornton 1995, 201-202).

The change in potential energy is equal to the work done by a force on a physical body. Thus, in terms of modeling human spaceflight policy decision-making as a classical potential well, a couple of points should be kept in mind. One is that while the physical body is trapped in the well, it tends toward oscillatory motion. The other is that the body requires more energy than that of the well to escape its confines.

For the purposes of this study, instead of a rounded pipe or curved surface of the Earth, the geometry of the well is best thought of as a square or rectangular box that is open at the top. In politics, the well is a funding well and a policy must have the required funding to be successfully implemented. The reason for the square shape of the well is simply because of the nature of policy funding. Either a policy does not have the necessary funding and is trapped in the well, or it does and escapes. This is a rather abrupt change in potential hence the abrupt square-shaped boundaries of the well. This distinction was made clear when the Augustine Committee told the Obama Administration that if it wanted a viable government funded space program, such a program required a certain level of assured funding. The alternative is simply to not have a program. To call for a program such as Constellation and then not fund it is to allow it to fail. In terms of this model, such a program is trapped within the funding well without the energy needed to escape.

The Quantum Potential Well

The quantum potential well model has been thoroughly developed (Landau and Lifshitz 1958, Bohm 1989, Shankar 1994, and Griffiths 2005 all contain excellent descriptions of the model from the physics perspective), and serves as an example of some of the basic ideas of quantum mechanics.

The quantum potential well model is slightly more complicated then the classical model, primarily because of the nature of particles in quantum physics. Hence, one must know something of both the particle and potential well to effectively apply the model. However, the well still represents an energy barrier in which the particle is trapped.

The interesting properties of the quantum potential well stem from the particle itself. What we normally refer to as a particle in reality, is as much a wave representing the probabilities of finding the “particle” at a given place and time. Where larger aggregate physical bodies can be described with properties such as position, velocity, and acceleration, particles can only be described with their probabilistic wave-function. To add another complication, this probabilistic nature means that these particles are subject to the Heisenberg Uncertainty Principle which states that the more that is known about a particle's position the less that can be known about its velocity. This means that either its *exact* position or its *exact* velocity can be known at any given time, but not both simultaneously. Hence, in quantum mechanics the best we can know is probabilistic information about particles, not because we lack a more complete understanding of the science, but because this is the nature of the microscopic world (For a more thorough description of the argument behind this see Griffiths 2005, 2-5).

The particle-wave dual nature leads to two interesting situations. The first concerns the nature of motion within the potential well itself. In classical mechanics there are two ways to view the motion of physical bodies. One is the aforementioned use of mechanical properties such as velocity. The other is to account for the energy contained in a body or system and how that energy is transferred to other parts of the system or to other systems. This view lends itself well to the potential well problem and is used extensively in quantum mechanics. However, unlike in classical mechanics, in the quantum world a particle can only have energy in specific amounts, multiples of a number known as the Planck constant (written as $\hbar$). We say that energy is quantized into these multiple amounts, hence the name quantum mechanics (all from the Latin cognate "quantus" for "how much"). For instance, light energy only exists in integer quantas based on the photon. One can encounter one photon of light or one million photons of light, but not half a photon of light. The photon, then, is a quantized packet of light, or electromagnetic, energy. Particles in the potential well can only have these quantized levels of energy. The lowest level is referred to as the ground state and any higher levels as excited states (Griffiths 2005, 32).

The other interesting property of particle in the quantum potential well is the ability to "tunnel" out of the well. In classical physics, a body must have a greater amount of energy than the height of the well to escape. This rule is inviolable. In quantum mechanics a particle can also escape the well by gaining more energy than the well itself, however this is not the only way it can escape. The wave-nature of particles allow them the probability to exist outside of the well even if they do not have the energy necessary to escape. This property is known as quantum tunneling and is one of the more peculiar traits of quantum mechanics. This peculiarity can be understood simply by knowing that that particles are not definite bodies as are normally encountered in macro-physics. For a deeper description of quantum tunneling see Bohm 1989, 232-242.

Differences in the Models

The classical and quantum potential well models lead to significant differences in the motion of physical bodies trapped within them. The classical model leads to oscillatory motion and requires a body have more energy then the energy level of the height of the well to escape. The quantum model leads to quantized energy levels and the potential for quantum tunneling as a means to escape the well.

Table 1: The Properties of the Potential Well Model

Classical Potential Well Properties	**Quantum Potential Well Properties**
Must have funding (energy) greater than that of the well to escape.	Can escape the well by quantum tunneling.
Leads to oscillatory motion.	Leads to quantized funding (energy) levels.

In physics, the difference between the classical and quantum worlds is based primarily on the size of the bodies under study. The quantum world is the more fundamental world of individual particles and small grouping of these particles. At this level particles are as much waves as discrete entities and their motion can only be described in a probabilistic fashion. Classical bodies are large-scale aggregates of particles and they obey the more common Newtonian laws of motion. While the individual particles in an aggregate body still undergo quantum effects, the bonds between particles constrain them and the body as a whole follows classical laws of motion. This is known in physics as the Correspondence Principle, stating that a system with a large number of quanta will act in a way consistent with classical mechanics.

It is interesting to ask if the political world follows a similar bifurcation. Individual decision-makers would represent particles in a quantum environment. Decisions are made based on imperfect information about the environment and fellow decision-makers, leading to choices made in a probabilistic fashion. However, when people group together in large organizations, bureaucratic constraint takes over and standard operating procedures ensure that decision-making is undertaken in a way more characteristic of classical physics.

Thus it is predicted that decision-making from organizations will lead to oscillatory motion and the need for funding at greater levels than the height of the well for a program to be successful. Decision-making from individuals will lead to quantum tunneling effects to allow a program to be successful at funding levels lower than the height of the well, as well as quantization of the funding levels themselves. Why are these effects expected? They are expected as natural effects of the similarity between physical motion and social decision-making. This study hypothesizes that individual human decision-making is probabilistic in nature just as particle motion is probabilistic, while organizational decision-making follows the more constrained classical rules of large physical bodies which are similarly constrained. If this hypothesis is true, each type of decision-making should display the above noted effects as a consequence of the type of mechanics they each follow.

Use of the potential well model with particular programmatic decisions being trapped in the well stems from its traits of simplicity and comparability. Potential wells exist in both classical and quantum mechanics and therefore have effects that can be compared. A particle trapped in a quantum potential well is also one of the more simple quantum situations that can be modeled. If this model is successful in explaining social phenomena, other more sophisticated models can be used to explain further effects.

The next two chapters will look at human spaceflight decision-making to determine if the potential well is a useful model to explain it and if this split between the quantum and classical in politics exists. Funding in human spaceflight in the period from 2004 to 2012 will be used to determine if the properties of quantum and classical bodies trapped in potential wells are present.

CHAPTER THREE: MEASURING US HUMAN SPACEFLIGHT FUNDING FROM 2004 TO 2012

The Recent Evolution in Human Spaceflight

The US human spaceflight program has been in operation since the late 1950s and early 1960s. Since that time, the program has had high points such as the Apollo program which took astronauts to the moon and consumed, at its height, from 60% to 70% of NASA budget and around 4% of the US national budget per year. There have also been low points, such as the gap between the end of Apollo and the launch of the first Space Shuttle. The constant, however, has been that human spaceflight has been a government program organized and implemented by NASA. While NASA has used private contractors throughout its history, the organization has always designed its own architecture, trained and utilized its own astronauts, and planned its own missions.

The period from 2004-2012 is one of great change for NASA. It is a period in which this preeminent set of powers in the hands of NASA has begun to erode. This is quite stunning because the beginning of the period heralded a completely opposite circumstance. In 2004 NASA was tasked with returning to the moon and in the next few years designed a program to do so that was essentially a larger, grander Apollo effort. NASA designed the launch and spacecraft architecture, set out to contract for manufacturing, and planned to train and send its astronauts on another grand voyage. However, Apollo level funding was not forthcoming and with the change in executive administrations in 2009, this effort began to collapse.

Yet NASA had begun doing something unprecedented in the years before, and this effort has come to replace the lunar program. Starting in 2006, NASA has begun to fund commercial enterprise, and not simply to manufacture launch vehicles and spacecraft that it had designed. These "NewSpace" companies have their own ideas for launch vehicles and spacecraft, and planned to conduct their own operations and launch astronauts themselves. They planned to sell these services and NASA would be one such customer out of many. The reality has been that NASA is, at this point, a necessary customer and that many of these companies require government subsidies to be viable, however this is a change that has been unprecedented in US human spaceflight history.

This chapter will detail this evolution with a focus on the budgetary concerns that have driven it. The narrative raises decision-making questions that may be answered by the use of the potential well model as an analogy.

The End of the NASA-only Era (2004-2011)

Decision-making for human spaceflight in the US lies with the president, congress, and NASA. In January 2004, then President George W. Bush gave a speech outlining his Vision for Space Exploration (VSE), redirecting the US human spaceflight program to go back to the moon by the year 2020 as a stepping stone to Mars. The VSE included an important set of exploration principles: the building of Earth orbit and lunar infrastructure, the use of in situ resource utilization on the moon as a learning tool for application to a manned Mars mission, and the inclusion of commercial enterprise for support of the International Space Station (National Aeronautics and Space Administration 2004, 5-7). The Space Shuttle would be retired in the 2010-2012 time-frame, after the construction of the International Space Station (ISS) was complete (National Aeronautics and Space Administration 2004, 22). The VSE, announced less than a year after and in response to the Space Shuttle Columbia disaster, was meant to articulate the future direction of US human spaceflight in light of the knowledge that the program that had been in place for nearly 30 years would have to come to an end in the near future.

With a vision articulated and supported by the president, then NASA Administrator Sean O'Keefe brought in Craig Steidle, a retired Navy Admiral and former director of the Joint Strike Fighter (JSF) program as the Associate Administrator of the Office of Exploration Systems, created to implement the VSE (NASA Tech Briefs 2004). The Exploration Systems Mission Directorate (ESMD) was conceived in order to develop the necessary technology and infrastructure. A Congressional Budget Office (CBO) study in September 2004 gave a budgetary analysis to the new initiative. NASA projected a total budget through 2020 of $271 billion with $95 billion for the VSE – $66 billion to place humans back on the moon and $29 billion for the robotic support missions (Congressional Budget Office 2004, 2, 11). The CBO, however, estimated a historical average cost growth rate of 45 percent for NASA's programs which would add $32 billion to the total budget costs through 2020 bringing this number to $303 billion (Congressional Budget Office 2004, 11). In 2005, the new NASA Administrator, Michael Griffin restarted the program design process through his Exploration Systems Architecture Study (ESAS) which outlined the Constellation program and its components, the Ares I and Ares V launch vehicles, Orion spacecraft, and Altair lunar lander (Seedhouse 2009, 6).

The ESAS became the official NASA plan for implementation of the VSE, a program that Griffin would describe as “Apollo on steroids” (ABCTechProd 2005). Furthermore, Congress would go on to endorse the program through NASA Authorization Acts in 2005 and 2008. The public, however, was concerned with the cost of the undertaking, Hurricane Katrina having devastated New Orleans only a month prior, and Griffin claimed a figure of $104 billion to return to the moon. The Government Accountability Office (GAO) in 2007 estimated the cost of the VSE to be closer to $230 billion over two decades, and the CBO found in 2008 that an additional $2 billion per year would be needed through 2025 to successfully implement the vision (Morgan 2010, 6). While reports continually noted the need for a larger budget, the VSE did not receive the funding that had been planned in 2004, due for the most part to political wrangling. In 2008, Congress reached a bipartisan agreement to grant an additional $2.9 billion to NASA for three additional Shuttle missions which was rejected by President Bush. He saw the bill as micromanagement of the space program by Congress, and furthermore, disliked a particular provision of the bill which called for deeper international cooperation within US human spaceflight (Powell 2008). Both Republican and Democratic lawmakers in Congress were critical of the president's decision, as US human spaceflight was again caught up in larger political battles.

The ESAS-based program was also not without its critics in the engineering community, with the most organized being the supporters of an alternative architecture known as DIRECT (formally Direct Shuttle Initiative). The DIRECT architecture, published in October 2006, constituted a much simpler, cheaper, and safer plan than that outlined by the ESAS, with one launch vehicle based on Shuttle and current launch facility hardware. Griffin's reaction to the plan, primarily made in a January 2008 speech to the Space Transportation Association, was to characterize it as too optimized for lunar transportation and incapable of cost-effective service to the ISS. DIRECT supporters believed that the overall cost savings of the architecture more than made up for any disadvantages. It is possible that by 2008, Griffin and the Congressmen who had supported the Constellation architecture felt that the program was too far along to make changes, and Griffin saw Constellation as his personal legacy (information on DIRECT from Seedhouse 2009, 219-238). It is also quite possible that NASA's natural bureaucratic tendencies simply lead the organization toward a program with increased costs over what was done in the past, to justify the need for ever greater funding. If DIRECT could get the same job done (returning US astronauts to the moon) for much less, NASA leaders likely saw the program as opening the door to substantially shrinking future budgets.

The administration of President Barack Obama took up the reins of government in 2009, and almost immediately the Constellation program entered a period of uncertainty. NASA leadership had to transition from the Bush administration to that of Obama, and this transition was a messy affair. Michael Griffin refused to cooperate with the process, especially with Lori Garver who was a former Associate Administrator and who would go on to become the new Deputy Administrator. Griffin feared any criticism of the Constellation program, especially from those who lacked an engineering background, though he would ultimately leave NASA in January 2009 (Orlando Sentinel 2008). For the next four months NASA would be leaderless, only adding to the confusion over the future of US human spaceflight, until Charles Bolden became the new administrator in May.

Upon initial review of the Constellation program, the Obama Administration believed it to be unsustainable (since by this time the economic crisis starting in 2008 was in full force) and tasked the Review of United States Human Space Flight Plans Committee, colloquially known as the Augustine Committee after chairman Norman Augustine, to give recommendations on getting

US human spaceflight back on track. The committee had four general objectives in making their recommendations, utilization of the ISS, missions to the moon and other destinations beyond low-Earth orbit, support for private commercial enterprise, and costs not to exceed NASA's then budget profile for exploration (National Aeronautics and Space Administration 2009). In October 2009, the committee's report agreed that the Constellation program was not viable unless funding was substantially increased. The committee could not make recommendations, as that function was outside of their charter; however, they listed a set of alternatives at various funding levels. For the implementation of the Constellation program as it already was, the report noted that NASA would need $3 billion more per year (Augustine et al. 2009, 96). Released around the same time, a GAO report in August 2009 found that the Constellation architecture had an underdeveloped business case and significant technological problems which would lead to schedule and cost overruns and make it difficult to estimate the program's true costs (Government Accountability Office 2009b).

The Augustine Committee report spawned a period of tension between the President and Congress over the future of Constellation. Through the 2010 Consolidated Appropriations Act, Congress forbade the termination of the Constellation program until directed, so as to ensure that there would be time to consider any coming changes. On April 15, 2010 President Obama gave a speech at the Kennedy Space Center refocusing human spaceflight away from the moon and instead to a 2025 asteroid mission, while ceding the responsibility for ISS cargo and crew servicing from NASA to the private sector. As far as the president was concerned, Constellation was over although it took the April 15, 2011 Continuing Resolution to officially end the program. This meant that in February 2011, $215 million was spent on Constellation, a program which at this point was nominally canceled, in fact was still the official US human spaceflight program, by law (information on Constellation cancellation from Smith 2011, 1-2). Once Atlantis landed in July 2011 the US lost its indigenous human space launch capability.

The Rise of Commercial Space Enterprise (2006-2012)

At the present time, the US has two ongoing efforts to regain human space launch capability, one is the ongoing space program through NASA, and the other constitutes various corporations' private efforts. There is some overlap stemming from a NASA program to support private space launch efforts, but these two efforts are quite different, in terms of philosophy and supporters if not yet in terms of business model.

In terms of NASA, under the 2010 NASA Authorization Act the agency is to develop a new heavy-lift rocket that utilizes legacy technology and is focused on manned missions in deep-space (to an asteroid in 2025 and Mars in the 2030s). This rocket, known as the Space Launch System (SLS), will utilize the Orion space capsule which was the only part of Constellation to survive, and is expected to cost $18 billion to develop including test flights and upgrades of the Kennedy Space Center. The SLS is meant to be ready for test flights starting in 2017. The rocket system has supporters in two US Senators, Kay Bailey Hutchison (R-Texas) and Bill Nelson (D-Florida), who have touted the initiative as a way to create jobs and have accused the Obama Administration of trying to strangle it in its crib after the Wall Street Journal leaked a NASA report that estimated the true cost of the system at $63 billion through 2025 (information on the SLS from Chow 2011).

The SLS and Orion vehicles continue to move toward an initial launch in 2017, and are seen to have congressional support (Halvorson 2012). At the same time, ATK is seeking to sell NASA on a launch system called Liberty, and based on their work on the Ares rocket as well as the French Ariane 5. They claim Liberty could be ready to fly in three years (Barbree 2012).

Along with the SLS, the 2010 law cedes operations in Low Earth Orbit (LEO), namely cargo and astronaut launches to the ISS, to commercial enterprise. NASA had been supporting private enterprise through the Commercial Orbital Transportation Services (COTS) program, although the amount of actual financial support that the program has generated is unclear. In 2006, when the program started, NASA signed Space Act Agreements with Space Exploration Technologies (SpaceX) and Rocketplane-Kistler to demonstrate cargo delivery technologies with an option for astronaut transportation (National Aeronautics and Space Administration 2006). These companies had been sharing $500 million in funding through the program, however a year later NASA canceled the agreement with Rocketplane-Kistler due to that company's failure to meet financial performance milestones (Morring 2007). Then in 2008 NASA awarded COTS contracts to SpaceX and Orbital Sciences for ISS cargo resupply services worth a projected combined $3.5 billion through 2016 (National Aeronautics and Space Administration 2008). Another company, PlanetSpace, which had formed an alliance with Lockheed Martin, Boeing, and Alliant Techsystems, missed out on the COTS contract and filed a protest which was denied by the GAO in 2009 (Government Accountability Office 2009a).

The most interesting part of the program is COTS-D, the section pertaining to launching manned missions to the ISS (the other parts of the program deal with various types of cargo launches). Funding of $150 million of the $400 million of the 2009 stimulus money meant for human spaceflight was given to COTS by an agreement between NASA and the White House, with $80 million of that meant specifically for COTS-D. However, the award proved controversial. SpaceX, the company which had made the most headway in rocket development with its Falcon system requested $350 million in stimulus funding for COTS-D, denied by a Congress which saw the program as benefiting only a single company. The acting NASA Administrator at the time, Chris Scolese, refused to even see the appropriated $80 million as meant specifically for COTS-D (information on COTS-D from Block 2009a). Senator Bill Nelson (D-Florida) questioned Scolese's refusal to use this money to fund COTS-D a month later yet backed off any attempt to be viewed as a champion of the program, instead claiming to be backing a new launch complex at the Kennedy Space Center. Meanwhile, Elon Musk, the owner of SpaceX was simultaneously supporting Nelson in a letter to the *Orlando Sentinel* to push the COTS-D agenda yet openly hostile to the new launch complex he saw as only useful to rivals of his company (Block 2009b).

Funding has also come through a related NASA program known as Commercial Crew Development (CCDev) which utilized $50 million of the American Recovery and Reinvestment Act stimulus for commercial space projects. In 2010, Blue Origin received $3.7 million for development of the Launch Escape System (LES) and work on their New Shepard launch vehicle, Boeing received $18 million for development of the CST-100 manned spacecraft (in collaboration with Bigelow Aerospace), Paragon Space Development Corporation received $1.4 million for development of life support technology, Sierra Nevada Corporation received $20 million for development of the Dream Chaser manned spacecraft (through their acquisition of SpaceDev in 2008), and United Launch Alliance (the joint venture of Lockheed Martin and Boeing) received $6.7 million to develop an Emergency Detection System (EDS) for their Atlas

V and Delta IV rockets (National Aeronautics and Space Administration 2011b). As part of a second set of funding later that year and totaling $296 million, Blue Origin, Sierra Nevada Corporation, and Boeing were selected again for awards of $22 million, $80 million, and $92.3 million respectively, and SpaceX received $75 million towards Falcon 9 and Dragon development (Bergin 2011b).

The CCDev program has spawned some interesting developments. One of which is the ongoing initiative to human rate existing launch vehicles, namely the Atlas V. In July 2011, NASA and United Launch Alliance announced an agreement to do just that so that the Atlas V could be paired with Dream Chaser, CST-100, or other spacecraft to launch astronauts (Bergin 2011a). Another concerns the proposals which were not selected for CCDev funding. While various companies submitted proposals which failed to get selected, two efforts for the second round of funding stand out. One is the effort by Orbital Sciences and its Prometheus spaceplane, which fell short because NASA did not believe that the coalition that the company put together, including Northrop Grumman, United Launch Alliance, and Virgin Galactic was as valuable as some other proposals (National Aeronautics and Space Administration 2011a). The other was a proposal by United Launch Alliance to continue flying the two newest Space Shuttles, Endeavor and Atlantis, at two missions a year until 2017 at a cost of $1.5 billion per year (Coppinger 2011). NASA believed that the price tag was too high and that other private efforts could do the same job at lower cost.

While the Obama Administration's plans stress the use of the private sector for operations in LEO, certainly not everyone is a fan. One of the most outspoken critics of these efforts is former NASA Administrator Michael Griffin who believes that the commercial sector is not yet ready for the risk associated with manned space travel (Achenbach 2010). Many in Congress have spoken out against the Obama plan including Senators Bill Nelson (D-FL) chairman of the Senate Subcommitee on Space and Science, Mary Landrieu (D-LA), Richard Shelby (R-AL) who has been very vocal against a commercial sector that he sees as competition for the Marshall Space Center and NASA space system manufacturing done in Huntsville, as well as Representative Bill Posey (R-FL) and former Representative Suzanne Kosmas (D-FL), both with constituents on the Space Coast. On the other side was Brett Alexander, the former President of the Commercial Spaceflight Federation (he was replaced by Craig Steidle in May 2011) who saw the move toward the private sector as a way to get US astronauts back into space sooner than Constellation would have (Klamper 2010).

A recent congressional vote has opened debate on how many private ventures NASA should be funding. Many congressmen, including Bill Posey (R-FL) and Sandy Adams (R-FL) want NASA to chose only one or two of the handful of companies that have received funding to move ahead (Reed 2012). They see this as a way to get one spacecraft into use more quickly while saving money. Detractors to this view believe that the competition between ventures will ultimately lead to a more efficient launch and operations industry with more choices. In terms of the funding, it is noted that NASA has spent $406 million in the past year on four private space ventures, with the program being recently boosted to $830 million. By comparison, each space shuttle launch cost around $500 million, the SLS program gets roughly $1.45 billion per year, and Orion another $1.5 billion per year (Reed 2012).

And yet the private sector continues to make slow but steady progress. SpaceX launched unmanned Falcon 9 flights in June and December of 2010, with the second flight consisting of a launch of the Dragon spacecraft which orbited and returned to Earth. The company launched the Dragon to the ISS for the first time in May 2012 through its COTS contract, although it has also raised $375 million in private funding (including $100 million from its founder Elon Musk). Moon Express is developing lunar landing technology, Blue Origin (owned by Jeff Bezos, the founder of Amazon) is developing the New Shepard vertical take-off and landing (VTOL) launcher design, Armadillo Aerospace (owned by John Carmack, a co-founder of id Software, which created the Doom and Quake video game franchises) is working on a launch vehicle, and Bigelow Aerospace (founded by Robert Bigelow, owner of Budget Suites of America) on inflatable space habitats. A newer venture known as Stratolaunch Systems is underway by Burt Rutan (whose company Scaled Composites made the first private astronaut launch in 2004 and won the Ansari X Prize) and Paul Allen (Deagon 2012).

The private sector is split between companies that focus on a partnership with NASA and servicing of the ISS, and those that are trying to launch a space tourism industry. On the tourism side, Scaled Composites and Virgin Galactic (owned by Richard Branson, founder of the Virgin Group) continue to work on the SpaceShipTwo launcher and Xcor Aerospace on its own vehicle. Both are currently working on suborbital trips for paying customers (Deagon 2012).

Measuring The Funding of Human Spaceflight

This study seeks to ultimately answer three questions: 1) Is the potential well model useful for explaining human spaceflight decisions, 2) are these decisions classical or quantum in nature (or is there some split between the two), and 3) why did the US program evolve from mostly government run to more reliance on the private sector in the 2004-2012 time-frame? To answer these questions first requires clear descriptions and explanations of the funding involved in human spaceflight in the 2004-2012 time-frame, as well as the key players in this area.

In terms of funding, on the whole NASA's budget has declined in the 2004-2012 time-frame. While the dollar amount has risen from $15.1 billion in 2004 to $17.8 billion in 2012, proportionally speaking this is a drop from 0.66 percent of the US budget in 2004 to 0.47 percent in 2012 (Rogers 2010). At the start of the VSE in 2004 NASA projected a budget of $271 billion through 2020 ($15.9 billion per year) with $95 billion for the VSE itself ($5.6 billion per year) (Congressional Budget Office 2004, 2, 11). The Congressional Budget Office added a historical average cost growth rate of 45 percent to give an estimate of $303 billion ($17.9 billion per year) (Congressional Budget Office 2004, 11).

In 2005, then NASA Administrator Michael Griffin quoted a figure of $104 billion ($6.5 billion per year) for Project Constellation, which was the embodiment of the VSE (ABCTechProd 2005). At this point, then, Constellation already required $1 billion per year more than the initial estimate. In 2007, the GAO gave an estimate of $230 billion over two decades ($11.5 billion per year) for Constellation and claimed an additional $2 billion per year through 2025 would be needed to successfully implement the program (Morgan 2010, 6). By this point, Constellation was suffering from underfunding, delays, and cost inflation. The Augustine Committee, in October 2009, noted that NASA would need another $3 billion per year to keep Constellation on track (Augustine et al. 2009, 96). The program was then canceled by the Obama Administration.

The Space Shuttle program, which was canceled in 2011 cost $209 billion over its four decade lifetime ($5.2 billion per year), or roughly $1.6 billion per flight (Wall 2011). The

International Space Station cost $100 billion to construct (1994-2010 period), but since it is an international effort only $50 billion of that was US funding ($3.1 billion per year) (Minkel 2010). Ongoing US costs for the station are slightly under $3 billion per year (Smith 2012a). Orion gets roughly $1.5 billion per year, and since its start in 2012, the Space Launch System program is being funded at around $1.45 billion per year (Reed 2012). The total cost estimate for the program is $18 billion over the five year period from 2012-2016 ($3.6 billion per year), with the rocket ready to fly in 2017 (Quick 2011), and $63 billion through 2025 ($4.5 billion per year) (Chow 2011). The program, then, is starting out already extensively underfunded.

In terms of funding private enterprise, NASA spent $500 million through COTS in 2006 on contracts with SpaceX and Rocketplane-Kistler (National Aeronautics and Space Administration 2006). In 2008 COTS contracts were awarded to SpaceX and Orbital Sciences totaling $3.5 billion in NASA spending thorough 2016 ($438 million per year) (National Aeronautics and Space Administration 2008). NASA spent $150 million of its 2009 stimulus money on COTS, however Congress denied a request by SpaceX for $350 million that same year (Block 2009a).

The CCDev program utilized $50 million from the American Recovery and Reinvestment Act to fund commercial space projects. In 2010, NASA spent a total of $345.8 million on CCDev, spread out over a handful of companies in increments from $1.4 million to $92.3 million (Bergin 2011b). In total, NASA had spent $406 million on funding private enterprise in 2011 (Reed 2012). In 2012 the Obama Administration requested a budget of $850 million for CCDev, however the Senate only appropriated $500 million and the House $312 million with the lack of funding due to cost overruns in the SLS program (Rosenberg 2011). At the same time, SpaceX raised $375 million in private funding ($100 million from its founder) by 2012 (Deagon 2012).

The key players in human spaceflight decision-making in the 2004-2012 time-frame consist of both individuals and organizations. The President of the United States (George W. Bush in 2004-2008 and Barack Obama in 2009-2012), the NASA Administrator (Sean O'Keefe in 2004-2005, Michael Griffin in 2005-2009, and Charles Bolden in 2009-2012), and key congressmen and business executives engage in individual decision-making. Congress and NASA collectively, as well as a growing list of private space firms constitute organizational decision-makers.

In terms of the decision-making itself, each player tends to focus on a distinct part of space policy-making. The president will support or disengage from a vision for a large-scale program. For example, a speech by George W. Bush began the VSE program although this speech did not specify the cost of the program nor how it would be implemented. These decisions were left to NASA. Barack Obama made the decision to cancel the Constellation program based on the information that it would require more funding than his administration was willing to allocate. In the wake of this cancellation, he substituted a vision for private enterprise to operate in LEO and NASA to work toward conducting deep space missions to asteroids and eventually to Mars. However, he also did not specify cost or implementation guidelines, leaving this to others. The president merely sent a signal that the previous program was too costly.

In space program policy-making there exists a myth that the president can make or break a long-term policy initiative. This myth stems from the memory of the Apollo program when President John F. Kennedy spoke of landing on the moon within a decade and Congress continued to fund the space program at a steady 3-4% of the US budget to accomplish the task

(Launius and McCurdy 1997, 244). In the years after, however, this has not again been replicated. For example, actual construction of the space station did not begin until long after President Ronald Reagan gave support to the program and it went through intense political wrangling. President George H. W. Bush's Space Exploration Initiative fell flat due to its cost, and the same fate ultimately waited the VSE program. Presidential support certainly gets the ball rolling, but it rarely induces Congress to fund programs at adequate levels.

While the president tends to articulate a vision for a particular human spaceflight program, the NASA administrator must oversee the way in which the vision will be implemented, and champion the implementation based on its initial budget estimate. These estimates have generally been significantly lower than what the program will actually require and with a timetable that is much more aggressive than what actually occurs. There are a handful of reasons for this, the administrator wants the program to be supported, believes sunk costs will spur ongoing funding once the program is underway, cannot account for unknown problems that can cause delays, and is tied to Congressional funding whose lack can cause further delays which then cause further cost overruns. Because of this tendency, however, government oversight offices tends to add a factor to NASA estimates to account for future cost overruns.

Individual key congressmen and business executives can secure extra funding or ensure funding that has the risk of being cut actually comes through. Space programs tend to be pork-heavy, and seen simply as jobs within the districts of key members of Congress. It therefore, gets their support during times when funding may be cut, and space programs commonly have to survive many votes that may cancel them in part or outright. With the post-2006 push for commercial space enterprise, the owners of such companies, for instance SpaceX's Elon Musk have personally requested further government funding which would be managed through NASA.

Finally, organizations also make decisions. Congress, as a whole, controls the space budget and uses this power to signal support for a particular program or to strangle a program which lacks support. However, the Congressional budget process is complex and includes links to other players. The importance of this process should be noted.

Early in the budgetary cycle, the President must send Congress a budget proposal, which consists of recommendations for the funding of government programs by the President and includes the space budget. Each congressional committee then submits their estimate for spending within their area of expertise to the House and Senate Budget Committees. In the House, the relevant body is the Subcommittee on Space and Aeronautics in the Committee on Science, Space, and Technology, while in the Senate it is the Science and Space Subcommittee of the Committee on Commerce, Science, and Transportation. The Budget Committees draft a concurrent budget resolution using these estimates and information from various reports and hearings, and reconciliation might be needed if discretionary spending is tied closely to implementing the budget resolution (Saturno 2004, 2-3).

The House and Senate Appropriations Subcommittees each draft an appropriations bill that is subject to numerous constraints. Possible constraints consist of needed authorization, funding that might be limited by legislation, and limits from the budget resolution. Revenue legislation must also be reported to the House Ways and Means Committee and Senate Finance Committee. It is these appropriations bills that become the budget (Saturno 2004, 3-5).

From this process, it can be seen that the Congressional space budget is subject to the constraint coming from a process including multiple individuals and groups of individuals, and this leads to a classical type of interaction. While Congress voiced support for the Constellation program numerous times, the legislature chose to chronically underfund the program which then became plagued with set-backs and cost overruns. NASA, as an organization, has a culture which while seen as technically proficient, is also seen as lax on safety and willing to hide the true costs of its endeavors in order to secure greater funding.

CHAPTER FOUR: US HUMAN SPACEFLIGHT FUNDING DECISION-MAKING AS A POTENTIAL WELL PROBLEM

Is Decision-making in Human Spaceflight a Potential Well Problem?

The first question this study seeks to answer is whether use of the potential well model is valid for studying decision-making in human spaceflight policy. To answer this, the budgetary situation in the US human spaceflight program during 2004-2012 should be compared to the potential well. The potential well models a physical body whose motion is trapped within an area due to the force from an energy potential. For policy, the well is a funding well and it constrains potential decisions based on the available funding.

The two potential well models, classical and quantum, both have distinct traits. The classical model requires a policy decision have greater funding than the height of the well to be successful and leads to oscillatory motion. The quantum well allows for the possibility of a policy to escape the well (be successful) without greater funding than the height of the well and also requires funding decisions to be quantized. What funding decisions in 2004-2012 display these properties?

The following table shows the budgetary cost of key programs in the 2004 to 2012 time-frame as compared to the traditional funding well height based on the Space Shuttle and ISS programs:

Table 2: HSF Program Budgets Versus Traditional Well Height

Program	Yearly Budget ($ billions)	Time-Frame	Cost Above or Below Traditional Well Height ($ billions)
Space Shuttle	5.2	Pre-2004 to 2011	
ISS	3.1	Pre-2004 to Post-2012	
Traditional Well Height (Sum of Space Shuttle and ISS Programs)	**8.3**	**Pre-2004 to 2011**	**0**
VSE/Constellation – 2004 NASA Estimate	5.6	2004 to Post-2012	-2.7
VSE/Constellation – 2004 CBO Cost Growth Estimate	17.9	2004 to Post-2012	9.6
VSE/Constellation – 2005 NASA Estimate	6.5	2005 to Post-2012	-1.8
VSE/Constellation – 2007 GAO Estimate	11.5	2007 to Post-2012	3.2
VSE/Constellation – 2009 Augustine Committee Report	**9 to 10**	**2009 to Post-2012**	**0.7 to 1.7**
SLS/Orion	3	2011 to Post-2012	
Funding for Commercial Enterprise	0.5 to 1	2006 to Post-2012	
Current Program (Sum of SLS/Orion, Funding for Commercial Enterprise, and ISS)	**6.6 to 7.1**	**2011 to Post-2012**	**-1.2 to -1.7**

To define the height of the funding well, it must be clear where human spaceflight funding comes from. It is taxpayer money whose budget is, for the most part, decided by Congress. It is key to understand then that Congress has the upper hand since it has many different choices in programs to fund, while NASA has no other source of funding (Broniatowski and Weigel 2008, 155). Furthermore, Congress funds programs based on getting the most “bang” for the lowest “buck”, and will cut funding if it believes a program can continue on without additional spending (Broniatowski and Weigel 2008, 155). Thus coming into the 2004-2012 time-frame, Congress was accustomed to a human spaceflight program which had been operating the Shuttle throughout the 1990s and early 2000s and was building the space station at the funding levels of $12-$14 billion for the space program as a whole (although this equates to a drop from roughly 1% to 0.6% of the federal budget, or $18 to $15.5 billion in 2007 constant dollars) over the time-frame. The Shuttle itself cost around $5.2 billion per year on average, and the station cost $3.1 billion per year on average, so Congress was used to spending roughly $8.3 billion per year on human spaceflight with the rest of the space program funding going to science, unmanned missions, and many other expenses. The well height was therefore at this $8.3 billion per year level, enough to have a human spaceflight program that could operate in Low Earth Orbit.

Thus coming into 2004, Congress was accustomed to funding the human spaceflight program at just over $8 billion per year which granted just enough funding for the Shuttle program to escape the well and be successful. Does this funding well model constrain human spaceflight decision-making? Most certainly, since NASA must either request more funding or cannibalize from other programs if more is needed, and is always under the threat of budget cuts leading to program cancellation. As Broniatowski and Weigel put it, "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 (2008, 151)." In fact, lack of funding in the 2004-2009 time-frame leading to program cancellation is exactly what occurred.

Over 2004-2009, the height of the well was at this $8.3 billion level. NASA would get slightly more funding (although always a decline in real terms) so that this height would at best stay at the same level, but the funding Constellation required shows how constraining the well would be. The initial 2004 NASA estimate of $5.6 billion per year through 2020 would have most likely produced a successful program and NASA could have bargained for a slightly higher human spaceflight budget and taken money from other programs (along with anticipation of the

Shuttle program winding down post-2010). It is telling that the CBO's cost growth estimate, done in the same year, led to a figure of $17.9 billion per year, as this number is staggeringly high given NASA's historical budget and would represent a nearly insurmountable well height.

In 2005, the NASA estimate was up to $6.5 billion per year, which while not yet an unreasonable number, showed that initial estimates were certainly too small. An interesting point here concerns how the program was viewed. It is likely that NASA saw Constellation as a replacement program for human space launch capacity plus a program to return to the moon, something that the Shuttle was incapable of. Any higher level of investment needed was for this additional capability. Congress tended to see the program as simply a replacement for human spaceflight and wondered why this capability would need so much greater funding. As time went on the cost continued to increase with: a 2007 GAO estimate of $11.5 billion per year and calls for at least $2 billion more per year to save the program, to the Augustine Committee's call for an additional $3 billion per year in 2009. This meant that NASA would need somewhere in the $9-$10 billion range for human spaceflight alone, or a call to Congress to fund $1-2 billion higher than the historical funding well height. In effect, the well height had grown to represent the funding level that a deep space human spaceflight program would need, around $9-$10 billion per year, however funding would only come in at the traditional level or lower. To be fair, cancellation of the Shuttle and cannibalization of science program would mean extra money for human spaceflight, but this was not enough to save Constellation from cancellation by the Obama Administration and Congress. The cost was so high and with such unchecked growth, that a gap in capability and a reset to a cheaper program was seen as a better option. Constellation would not only never escape Earth orbit, but the program could never escape the funding well.

Taking the place of Constellation is a split between the SLS/Orion and funding for private enterprise. SLS/Orion gets a combined roughly $3 billion per year while the programs which support private enterprise in the area of $500 million to $1 billion per year (private enterprise is being funded at much smaller increments and sporadically so it is difficult to get a handle on how it will be funded in the long-term). SLS/Orion is seen as being underfunded, and this fits with the potential well model. If the well height for the launch vehicle portion of a LEO program is around $5 billion per year, than SLS/Orion will likely not be completed on time. Whether this ultimately causes the program to fail is not yet known, but it is likely to cause further setbacks leading to the need for more funding. The private sector funding is meant to fill in the gaps, but the potential well model shows that these companies will need extensive private funding to be successful. An interesting point, however, is that private companies may be more efficient allowing the well height to decrease, but this remains to be seen.

As a model, the potential well is a good framework for explaining human spaceflight policy decision-making. These programs are indeed highly constrained by the level of funding they receive, and risk cancellation if they do not receive enough to escape the well.

Is Decision-making in Human Spaceflight Classical or Quantum in Nature?

If the potential well model is a good framework for evaluating human spaceflight policy decision-making, can it tell us something more about this area? An interesting question is whether there is a split in the political world, as there is in the physical, between the behavior of individuals and aggregate bodies.

In physics, aggregate bodies follow classical, Newtonian, mechanics. In the potential well, these bodies must have more energy than the height of the well to escape and also tend to undertake oscillatory motion when trapped within the well. Individual particles follow the laws of quantum mechanics and are based on probabilistic functions. They can use quantum tunneling effects to escape a potential well that is higher than their energy level, and must have quantized levels of energy within the well. Are these properties found in the thinking behind decision-making?

To explore whether this split exists in the world of politics, the funding decisions that have been discussed previously must be linked to the entity which made the decision. The thinking behind the decision will be evaluated to determine is it has any of the four traits. If it displays oscillatory motion or the need to escape the well by an increase of funding, it is characterized as classical thinking. If instead the entity believes that the well can be escaped at lower funding levels due to probabilistic effects, or the decision displays quantization, it is characterized as quantum thinking. This characterization is then linked to the status of the entity as an individual or organization to see if individuals are more likely to follow quantum thinking and organizations follow classical thinking. Even if these are only characterizations, can the potential well model give an explanation for the reasoning behind decision-making?

How can each of these properties be operationalized? Each describes a particular physical process as applied to characterize a particular facet of human thinking. The concept that a program will need more funding to escape a potential well is fairly simple to see in human thinking. The decision-maker will make choices under the belief that funding must increase as the only way to make a program successful, and that lack of this funding will lead directly to program cancellation. The concept of oscillatory motion will lead to decisions which at times will fund a program generously and at other times will underfund a program. Such thinking leads a program to oscillate high and low, but to ultimately be gaining no ground. The program will be marked with delays, leading to cost overruns.

Quantum Mechanics is a more complicated science, and therefore the quantum characterizations are more challenging to notice in human thinking. The concept of quantum tunneling provides an alternate means by which a program can be successful. This property is based on the probability that a particle can leak out of the potential well at a lower energy level due to its wave nature. Quantum tunneling is more likely when the well is weaker and smaller (Bohm 1989, 240). In human thinking, tunneling will be characterized by the belief that if funding is not forthcoming, all is not lost. A program can still gain a weaker level of support in other areas (as jobs programs, split into smaller programs, etc.) that have the probability to allow it to succeed at a later time. Finally, the concept of quantization entails a program being only funded at levels that are multiples of some basic funding level. In physics, this is an energy level known as the Planck constant, and the energy levels of particles in a potential well must be multiples of this constant. The Augustine Committee referred to an “entry cost” to human spaceflight, under which no program could be successful, as well as the lack of a “cost continuum” (Augustine 23). Unfortunately, the Augustine Committee report does not make this number clear. However, it can be seen if the levels of funding of various programs seem to be multiples of some basic cost.

In 2004, the Space Shuttle program was a long-running, ongoing program. By this point in the Shuttle program, it was getting the funding necessary to escape a potential well for a LEO-only program, and it had the support of all of the key players, the president, congress, and NASA. Simultaneously, the ISS program was supported and in the process of construction. This entire human spaceflight effort cost roughly $8 billion per year.

The first decision to consider is President Bush's announcement of the VSE. The president's vision did not contain a discussion of cost, but only that NASA was to “implement a sustained and affordable human and robotic program to explore the solar system and beyond (National Aeronautics and Space Administration 2004, 5).” A likely expectation was that the program would need greater funding but not at levels that were drastically higher than what NASA was already getting, since the agency would use funds from other programs (Space Shuttle and ISS) as they ended to support the new effort. This thinking is effectively classical in nature, as it is characterized by belief that the new program would acquire additional funding, although under the impression that not much more would be needed.

The next decision is that of the Constellation program architecture being designed out of the VSE. While deep technical details of the architecture can be attributed to NASA as a whole (due to the number of teams within the organization that worked on it), as a whole program, Constellation was most supported by the person of former NASA Administrator Michael Griffin. Unlike the president, Griffin was well aware of the cost of Constellation, a number which continued to rise over the early years of the program's development, from $5.6 billion to $6.5 billion, and then finally to the level of $9-10 billion per year. Griffin displayed classical thinking in his belief that congress would continue funding a program which quickly doubled in cost. As it became apparent that congress would not fund the program, he did not try a different approach that would have been characterized as quantum thinking, such as support for a cheaper program like DIRECT or human-rating an existing rocket.

Over the years from 2004 to 2009, congress as a whole made decisions to underfund the Constellation program, while continuing to profess support for it. Congress did this because it did not truly support a program which was significantly more costly than what it had become used to paying for the Shuttle. Again this shows classical thinking since without funding, the program would ultimately fail. To add an even stronger case to classical thinking in congress, the body was the most directly responsible for oscillatory motion in the Constellation program in these years. Sometimes congress would choose to give additional funding to the program, with the most notable being the additional $2.9 billion in 2008 which was rejected by President Bush. For the most part, the body chose to underfund Constellation and the program suffered from delays and cost-overruns due to this choice.

In 2009, the Augustine Committee gave its report noting that Constellation would need to be funded at the $9-10 billion per year range to be successful, which led President Obama to call for the program's cancellation. In place of a fully government funded space program, NASA was now to put serious effort into support for private enterprise in LEO while concentrating on deep space exploration. This shows quantum thinking. Since the Constellation program was seen to be too expensive and would not be funded at a level that would allow it to escape the funding well, an alternative was needed to ensure program success. That alternative was keeping government funding at levels that would be sustainable while utilizing the private sector to manage a, hopefully more efficient and affordable, program.

The NASA-run government side of the new US human spaceflight program came from a decision to pursue the SLS and Orion. This decision has its principal base of support in congress.

The SLS is a heavy launch rocket, which would effectively be the combination of the Constellation's Ares I and Ares V rockets, while Orion maintains its original design as the Constellation manned spacecraft. The decision to move to this program also shows quantum thinking, since in a way this program seems to show a thought process meant to keep Constellation alive. The spacecraft has remained the same and NASA still seeks to build a heavy-lift rocket capable of mission to the moon, Mars, and asteroids. The goal is to do it in a way that will continue to attract funding, yet this may still be a problem since the SLS is currently seen to be underfunded. The ultimate destiny of the program is still unknown, but if chronic underfunding continues it will ultimately fail.

Finally, the decision to require NASA to fund private enterprise represents a fundamental change to US human spaceflight policy. While NASA has been doing so in small increments starting in 2006, the change was championed by President Obama and can be characterized as a quantum decision. This change stems from thinking on how to continue a viable space program during a time of recession at a reasonable cost to the government. Subsidization of the private sector also solves one of the problems inherent in classical thinking, the oscillatory motion congress tends to sow into space funding. Funding for the private sector is done in tens or hundreds of millions of dollars, much small increments than the billions that go into direct programs, and it is spread out over a handful of companies that also have private investment. Congress can choose to over or underfund this program in any given year and the private funding will smooth out the ups and downs. While these programs still suffer delays, such delays should not be as debilitating to the success of the space system. In the future, if these companies are profitable, funding in the space industry could become much more stable leading to greater program success.

It should be noted that the above discussion did not include the property of quantization in a definite numerical sense. While the Augustine Committee may be correct in that a basic level of funding exists and there is no funding continuum, the data does not show funding to be based on multiples of any basic cost. The data does show that the level of around $8 billion per year can get support (and lower levels do as well), while a level closer to $10 billion or more per year cannot. With the funding of private efforts, the levels are much lower than has been traditional for direct funding of government run programs. These levels, in the tens and hundreds of millions of dollars, also do not seem to be multiples of any more basic cost. However, quantization can be seen in terms of measurable programmatic benchmarks. Some number of Shuttle launches must have been made at some cost per flight to build the ISS, and in fact decision-makers like the NASA Administrator tend to stress mission success in quantifiable terms such as the number of flights of a space vehicle. Further detailed exploration should be made into the property of quantization within programmatic decision-making before its existence can be determined.

Why Did the US Human Spaceflight Program Evolve as it Did From 2004-2012?

The US human spaceflight program underwent a fundamental change during the 2004-2012 time-frame. Toward the beginning, the program was following the same tradition it had since its genesis in the late 1950s, operating as a government funded and run program. While NASA has always subcontracted to private corporations, the agency always controlled mission planning, designed its system architecture, and launched its own vehicles. Starting in 2006, and with presidential support after 2009, NASA has begun to invest in private enterprise in a wholly different way. Now it is private companies who design and build the vehicles, launch them (albeit with some level of NASA assistance), and plan for missions from both government and private clients. NASA continues to run a human spaceflight program, but such work is seen now as a partnership with efforts of private enterprise. What dynamics have occurred to support this evolution? The use of the potential well model to explain human spaceflight funding can help to shed light on the answer to this question.

To understand this evolution, first the actions and responsibilities of each actor must be understood. At the highest levels of US government are the president and congress. The president defines a strategy or set of overarching goals, but not details over how those goals should be reached. Historically, presidents have not felt space policy to be important enough to be a top policy initiative, especially post-Apollo. Presidents spend very little political capital fighting for space programs. Congress as a whole is responsible with the funding of space programs, and this is done on a yearly basis. Congress tends to only want to fund space programs with just enough to have a handful of capabilities: human access to orbit, access to the ISS, and the capability to launch satellites. Programs that go beyond this, for instance sustained manned mission to the moon or Mars tend to be rejected. Individual congressmen tend to support space policy if their district receives jobs due to these programs. Otherwise interest is small or non-existent.

Below the federal branches, is NASA, the bureaucratic organization tasked with care of the US civil space program. NASA runs a gamut of programs, and human spaceflight is only one part of what they do (albeit a part that requires the lion's share of funding). NASA has traditionally decided what technology should be built to accomplish space policy goals, subcontracted the building of hardware, and maintained and launched that hardware. The NASA administrator, especially Michael Griffin, has generally seen the architecture and operation of human spaceflight programs as representative of their personal ideals.

Finally there are other players such as businessmen and state and local politicians who may have a stake in particular space programs, but have not traditionally been part of the overall decision-making process. As part of the evolution toward privatization, private industry has become a much more integral player and has gained decision-making capabilities.

In 2004, when the VSE was announced, President Bush made certain assumptions about the cost of the new program. The expectation was that NASA would subsidize the cost of the VSE by ending the shuttle program in around 2010 and the ISS program in around 2015, as well as pulling funding from other programs. This would allow the cost of the VSE to be only slightly more than NASA's budget at the time, and the president claimed that the program would get the funding it needed.

As the VSE morphed into the more concretely defined Constellation program, it became clear that the cost would be significantly larger than the levels of funding which NASA had been receiving. While the president makes budget requests each year, it is up to congress to determine the level at which human spaceflight is to be funded. Congress as a whole was unwilling to spend significantly more than NASA had been getting for human spaceflight, and the new capabilities (rockets and spacecraft that would allow manned missions to the moon) was seen as not worth the cost. At the same time, particular congressmen whose districts or states benefited from the space program, fought to support Constellation. Senator Kay Bailey Hutchison (R-TX), Representative Tom DeLay (R-TX), Representative Gabrielle Giffords (D-AZ), Senator Bill

Nelson (D-FL), and Richard Shelby (R-AL) are a few of the congressmen who consistently supported Constellation.

The split in support from congress (from the body as a whole versus from individual members) causes a bit of schizophrenia in what this body does for the human spaceflight program. Throughout the Constellation years, individual supporters would vouch support from congress for the program while at the same time, the program never got the funding it needed. If funding is the true way to gauge support, congress simply made the case that it was unwilling to get behind the program at the level of funding that NASA Administrator Griffin was requesting.

Constellation was not the first moon-Mars human spaceflight program to be considered by the United States. The idea to evolve the Apollo program to aim for Mars in the 1970s, and the Space Exploration Initiative in the 1990s were both rejected also for cost reasons. Constellation was becoming another unsupported program that would be delayed considerably before being finally abandoned. Constellation could have easily been left to suffer delays and capability cuts until, over time, parts of it were built and operated. Two unique situations made this impossible. The first was that nearly everyone agreed that the Space Shuttle could not be operated past the 2010-2012 time-frame. The US was going to lose its manned launch capability yet it needed a way to get astronauts to the ISS. The only conceivable way to do this was to buy flights from Russia, and this was seen as a blow to pride. The other situation was the economic recession starting in 2007-2008. Once the full effects of the recession were underway it was clear that the human spaceflight program would have to make due without greater financial support. The trick then was how to maintain human spaceflight capability given the new reality.

When the Constellation program was finally canceled by the Obama Administration to focus greater attention on private enterprise, these private efforts were already a few years old and were already getting NASA funding. However, they were not seen as an integral part of the US space program. After Constellation was canceled, they became the means by which the US would maintain human spaceflight and cargo resupply to the ISS. The potential well model helps illustrate this change in thinking. In the traditional government-run model, NASA and congress could only operate in a classical sense. Once a goal was articulated, the space program simply needed the funding to reach the goal (or in the model, to leave the well). Lack of funding meant lack of support, and generally lead to cancellation of the program.

The inclusion of private enterprise allows a more quantum sense of funding to take place. Instead of surmounting the well, the idea is to make decisions that allow for tunneling out of the well. Instead of requiring public funds for the full cost of human spaceflight, a sharing agreement with the private sector can allow for this tunneling to take place.

Inclusion of the private sector has occurred in such a sweeping way because it solves not only the tunneling problem, but the oscillatory problem as well. Traditional programs had required large levels of funding, billions of dollars, being allocated over long time periods (decades or more). Such funding schemes do not fit well with the way the US government operates, in which presidents hold office for 4-8 years and congress budgets on a yearly basis. Due to this, human spaceflight programs would be planned for decades of steady funding and when funding would change from year to year, delays would occur and cause cost increases. In other words, congress would withhold too much funding in one year, cause a delay and cost increase, and then try to solve the problem by giving slightly more in another year. The delay would more than make up for the extra money, and at least during the Constellation program, this extra funding would typically be orders of magnitude less than what the program required. This behavior from congress caused an unstable oscillation in the way human spaceflight programs received funding, a situation that the potential well model shows is typical of classical systems.

In a partnership with the private sector, these oscillations can be smoothed out. Instead of one massive program requiring consistent large sums of funding, private sector support is given across a handful of companies in much smaller increments, and these companies use private funding to pick up the slack. Congress can grant funding year to year in much smaller increments, tens or hundreds of millions of dollars instead of billions, and funding can be tied to contracts and milestones. Simultaneously, NASA is running the SLS and Orion programs at much lower cost then Constellation as whole would have been. This new organization allows for these programs to tunnel out of the well in the quantum sense and avoid the problems associated with classical motion in the well. For this reason, the human spaceflight program was forced to evolve. The only other option was to cease entirely.

The Link to Generalized Decision-making

The goal of the above experiment was to link decisions in US human spaceflight funding in the period from 2004 to 2012 to both classical and quantum properties and to the nature of the decision-making as an individual or organization. The expectation was that individual decision-making would be linked to quantum properties and organizational decision-making to classical properties.

The two classical properties were linked very closely to congress, an organization and the traditional source of funding for human spaceflight. In terms of oscillatory motion, it is congress that causes this phenomenon within the space budget by choosing to not fund consistently over time. Congress also views a space program as incapable of being successful unless it has the funding necessary to escape the funding well. However, this view is also shared by the NASA administrator, an individual decision-maker.

The two quantum properties could not be linked specifically to individuals, but instead are most notable as the outcome of small group decision-making (organizations that might be most similar to groups of atoms or molecules in physics). The new commercial space enterprises are, for the most part, small companies whose decision-making is done primarily under the vision of individual founders. It is these enterprises that are utilizing private funding and more efficient space systems as a means to tunnel out of the well without the requirement of enormous budgets.

While the quantization of energy (funding) levels was only vaguely apparent, the general idea can best be attributed to the Augustine Committee, a small group of people. The Augustine Committee found that human spaceflight funding most likely has a base level for a program to be successful, but their report did not examine what such a level of funding might be. There is also no evidence for the levels to be quantized multiples of any base number. However, this is something that may not be noticeable without better data collection or present in terms of measurable programmatic benchmarks. It is certainly an area that could benefit from further study.

From these results, it can be seen that the bifurcation between the classical and quantum in human decision-making is not as black and white as it is in physics, however it does seem to be present. Certainly further study can shed more light on this bifurcation and its deeper nature.

A similar experiment that is grounded deeper in the physics behind this bifurcation may lead to a more clear answer to whether human decision-making is similar and in what specific ways it might be.

CHAPTER FIVE: CONCLUSION

This study has three basic goals: to utilize the potential well models to understand the evolution in space policy in the 2004-2012 time-frame, to search for a bifurcation between the individual and aggregate levels of analysis in political science that mirrors that in physics, and to explore whether physical models can be of use in explaining political phenomena. Were each of these goals successful?

In utilizing the potential well models to understand the evolution in space policy in 2004-2012, this study is successful. The study was meant to test certain assumptions, that funding is the best representation of support, and that funding decisions are constrained. The potential wells models represent a more formalized illustration of these assumptions. Through such formalization is it possible to learn more about human spaceflight decision-making?

The power of comparison, in this case human spaceflight decision-making to the potential well models, is that the models exhibit additional properties which may or may not be present in the actual phenomena under study. If the phenomena do exhibit these properties, other related models can be tested which may, in turn, help in the discovery of other properties. The potential well models certainly work in this fashion. Employment of the models was based on the assumptions of funding and constraint mentioned earlier. However, the models made other properties clear. Funding for a program would have to surmount the height of the funding well if a program was to be successful, which is most definitely true in the classical model. However, in the quantum model, tunneling effects could allow programs to succeed while remaining underfunded. The classical model also results in oscillatory motion, while the quantum model leads to quantized funding states. Were these properties present in human spaceflight policy in 2004-2012?

Before that question can be explored, it should be noted that interpretation of these properties represents a serious issue in this study. The models and their properties come from physical science and were developed to explain the motion of physical bodies. In adapting these tools to human decision-making this study must be clear about what exactly the models represent and what their properties mean. Interpretations must be made and variables operationalized, and there are more than one potential interpretations. Thus, certain interpretations are made, and it is left to the reader to determine if such decisions were sound. It is certain that another could see things quite differently.

When the 2004-2012 time-frame is considered, one property tends to stand out and is clear to see. It is the belief that a funding decision must result in a program that is funded at a higher level than the height of the well for success to occur. While some actors would fight for increased funding for the Constellation program whereas others did not support this, there was fairly broad agreement that more funding was needed for the program to succeed, as there is now with the SLS program. This idea is part of classical decision-making and it was clearly present.

The property of tunneling in the quantum potential well model is present in this time-frame but requires some interpretation. Tunneling in quantum mechanics is a complex process relying on the probabilistic nature of particles. It is also a topic that is still under active research in physics. The interpretation for this property in space policy decision-making was the presence of any method by which a program could succeed without enough funding to escape the height of the funding well utilizing traditional government funding. This leaves two methods. One is the acquisition of funding from other sources, such as the private sector. This method can still be considered classical decision-making, just with non-government funding. Since this represents a new twist in US human space-flight decision-making, however, it was interpreted as quantum decision-making. The other method is utilization of any means to make a space program more efficient and require less funding to operate. These methods allow the program to escape the well by tunneling out from within, and represent quantum decision-making.

The property of classical oscillatory motion was also present, but required interpretation. In classical physics, constrained motion leads to oscillation and this can be seen in a pendulum. The pendulum cannot leave the string (escape the well) unless it has the energy to do so, but while constrained will move only back and forth. In human spaceflight decision-making, this is seen in how congress tends to fund programs. When congress is unwilling to fund a program at a level needed to escape the well, the program can receive a yearly budget that sometimes rises and sometimes falls, but keeps it firmly within the funding well. Supporters will believe that next year they will get the funding they need, detractors will believe that if the money cannot be spared the program must simply operate on less, and the program slowly oscillates within the well until it dies.

Finally, the property of quantization is the easiest to test for from the data itself and, in this capacity, was found to be lacking. As a classical potential well leads to oscillatory motion, so a quantum well leads to quantized energy levels. For a funding well, this would mean that quantum decision-making would lead to funding levels that are multiples of a base number. Funding data, however, showed levels to be on a continuum and not quantized. However, in terms of quantifiable programmatic benchmarks such the number of launches of a space vehicle or number of modules to construct a space station, this principle may indeed be an important part of human spaceflight decision-making. This property would have to be tested further as it is unclear what the causes of the exact levels of funding are, however, a look at the data for Constellation, the post-Constellation programs, and funding for the private sector did not reveal a clear quantization effect.

While the slightly ambiguous nature of these results (three properties present and one lacking) shows that further study is needed, the potential well models were successful in helping to discover new effects at play in human spaceflight decision-making. The models were selected based on certain assumptions, those assumptions proved to be cogent to the phenomena under study, and new properties were discovered using the models that proved to be cogent as well.

The second goal, that of a search for a bifurcation between the individual and aggregate levels that mirrors the one in physics proved to be unclear. A split between these levels certainly exists in political science and has been noted and studied for many years. The split generally represents two distinct schools of political science, with political psychological methodologies used to study individual decision-makers and bureaucratic methodologies for organizations. What is unclear is if this split in political science mirrors the split in physics in which the individual level follows quantum mechanics laws and the aggregate level follows classical laws.

If this bifurcation exists in political science, it would be expected to see it in how different individuals and bodies make decisions. The president, NASA administrator, and individual congressmen should always exhibit quantum decision-making, while congress, NASA as a whole, and other organizations should exhibit classical decision-making. While this was not clearly the case, it could be that this is due to interpretation effects and not because of an underlying lack of such a bifurcation.

The reason for this bifurcation in physics is based on fairly deep and elegant laws pertaining to the nature of the universe. While this certainly does not mean such a phenomena exists in social and political science, it is worth exploring in more detail. This study was unclear as to the nature of this bifurcation, but it is advised that further exploration of this phenomena be undertaken.

Finally, has this study shown that physical models can be useful in political science (and potentially all of social science)? As the use of the models has lead to the discovery of additional principles at play in human spaceflight decision-making, the answer to this question is a resounding yes. Physical models tend to interlock with each other, with one model relying on underlying rules that are based on other related models. Political science woefully lacks such a framework, and the use of physical models can help to discover it. This does not mean that models should be taken from physics with no basis for application. It does mean that when a basis is present, political scientists should not shy away from physical models.

Even when they are not present, the type of thought processes that allow for the creation of such physical models can be used to construct political models from first principles. The use of such models can be done in a better fashion than in this exploratory study. One way to do so is to embrace the physical sciences use of formal structure. Mathematics is the language of logic thinking and modeling represents a formal way to discuss phenomena. These tools help to ensure that scientific exploration of phenomena occurs, and that variables are clearly understood and correctly related. They are mentally demanding but they drastically reduce room for interpretive errors. Further study should make better use of such tools, even if the initial topics under study must necessarily be very basic. Political science should strive to start from basic first principles and build an interlocking framework of models and relations between variables.

Another improvement can be made with the data itself. For this particular study, budgetary data was needed for human spaceflight programs in the 2004-2012 time-frame and this data was collected from many different sources. Some of these sources claim conflicting numbers, and this occurs for various reasons. NASA does not always account for programs in the same fashion from year to year, and programs change names and are organized under different headings from year to year, sometimes for the purpose of making financial tracking hard to accomplish. Programs also have various budgetary numbers attached to them, making it difficult to note the actor responsible for a given funding decision. A program may have some standard yearly level of funding that was agreed upon at its outset, and a different level of funding in any given year for the amount the president requests, the amounts that the house and senate appropriate separately, and then what finally becomes the budget. On top of that incongruity, are various individual congressmen who request different levels of funding and the budgets of the new commercial enterprises. In a future study, this data should be collected in a more systematic fashion. It should be complete, organized in a way that allows for yearly comparisons, and clear enough to allow specific actors' decisions to be noted.

A recent New York Times article by Jacqueline Stevens has made the assertion that political science cannot be predictive, likening attempts to be so as akin to a chimp randomly throwing darts at charts of possible outcomes on a wall (Stevens 2012). This study seeks to improve political science's (and social science's) predictive capabilities by utilization of physical models, but more so by stressing that a change in thought process is needed. Stevens is correct in stating that the outcomes of probability and statistical studies should not be taken for knowledge. Rein Taagepera has argued the same point, going so far as to show that political science methodology was unable to discover a known physical equation, the law of gravitation, from statistical analysis of data points (Taagepera 2008, 14-22). Instead, political science practitioners must become more scientific in their thinking, replacing statistical studies for models built on interlocking equations that show relationships between variables that are rigorously defined and measurable. This study seeks to harken back to the early days of the behavioral revolution and offer a different path for what scientific study could mean in political science.

While a future study should benefit from these improvements, the results found here represent a first exploratory utilization of the general principles expressed earlier. Even if some of the results are unclear, this study shows that physical models can be of use in political science. In the most general sense, this study argues for multidisciplinarity which can only help to improve the techniques and utility of all fields in which practitioners choose to learn from each other.

LIST OF REFERENCES

ABCTechProd. 2005. "Apollo on Steroids." *ABC News*, September 20. Accessed February 4, 2012. http://abcnews.go.com/blogs/technology/2005/09/apollo_on_stero/.

Achenbach, Joel. 2010. "NASA budget for 2011 eliminates funds for manned lunar missions." *Washington Post*, February 1. Accessed February 7, 2012. http://www.washingtonpost.com/wp-dyn/content/article/2010/01/31/AR2010013101058.html.

Allison, Graham, and Philip Zelikow. 1999. *Essence of Decision Second Edition*. New York: Addison-Wesley Educational Publishers Inc.

Art, Robert J. 1973. "Bureaucratic Politics and American Foreign Policy: A Critique." *Policy Sciences* 4:467-490.

Augustine, Norman R., et al. "Seeking a Human Spaceflight Program Worthy of a Great Nation." *Review of U.S. Human Spaceflight Plans Committee*. Accessed on February 4, 2012. http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf.

Barbree, Jay. 2012. "Space veterans offer NASA their Liberty launch system." *MSNBC*, May 9. Accessed May 15, 2012. http://www.msnbc.msn.com/id/47363362/ns/technology_and_science-space/#.T7JkcsX0-1k.

Berger, Brian, and Dan Leone. 2012. "Shrinking NASA Budget Forces Tough Trade-offs." Space.com, February 21. Accessed May 15, 2012. http://www.space.com/14642-nasa-budget-cuts-tradeoffs-exploration-spaceflight.html.

Bergin, Chris. 2011a. "NASA and ULA agree SAA to complete the human rating of Atlas V." NASA Spaceflight, July 18. Accessed February 7, 2012. http://www.nasaspaceflight.com/2011/07/nasa-ula-saa-complete-human-rating-atlas-v/.

Bergin, Chris. 2011b. "NASA oversight of CCDev-2 Partners reveals progress milestones." *NASA Spaceflight*, August 1. Accessed February 7, 2012. http://www.nasaspaceflight.com/2011/08/nasa-ccdev-2-partners-reveals-progress-milestones/.

Block, Robert. 2009a. "COTS D – Commercial Human Spaceflight to get at least $80m." *Orlando Sentinel*, April 29. Accessed February 6, 2012. http://blogs.orlandosentinel.com/news_space_thewritestuff/2009/04/cots-d-commericialhuman-spaceflight-to-get-150m.html.

Block, Robert. 2009b. “Is Sen. Bill Nelson flip-flopping on NASA's COTS-D space program?” *Orlando Sentinel*, May 28. Accessed February 6, 2012. http://blogs.orlandosentinel.com/news_space_thewritestuff/2009/05/is-senator-bill-nelson-flipflopping-on-nasas-cotsd-space-program.html.

Bohm, David. 1989. *Quantum Theory*. New York: Dover Publications, Inc.

Broniatowski, David A., and Annalisa L. Weigel. 2008. “The political sustainability of space exploration.” *Space Policy* 24:148-157.

Chow, Denise. 2011. “NASA Unveils New Giant Rocket for Deep Space Missions.” *Space.com*, September 14. Accessed February 6, 2012. http://www.space.com/12941-nasa-unveils-giant-rocket-space-launch-system.html.

Congressional Budget Office. 2004. “A Budgetary Analysis of NASA's New Vision for Space Exploration.” September. Accessed February 6, 2012. http://www.cbo.gov/ftpdocs/57xx/doc5772/09-02-NASA.pdf.

Coppinger, Rob. 2011. “NASA weighs plan to keep space shuttle until 2017.” *MSNBC*, February 3. Accessed February 7, 2012. http://www.msnbc.msn.com/id/41397955/ns/technology_and_science-space/#.TzFhGfnQe1k.

Deagon, Brian. 2012. “Commercial Space Industry Gets Ready For Takeoff.” *Investor's Business Daily*, January 12. Accessed February 7, 2012. http://news.investors.com/Article/597597/201201121722/entrepreneurs-see-stars-in-space-race.htm.

Government Accountability Office. 2009a. “B-401016; B-401016.2, PlanetSpace, Inc., April 22, 2009.” April 22. Accessed February 6, 2012. http://www.gao.gov/decisions/bidpro/401016.htm.

Government Accountability Office. 2009b. “Constellation Program Cost and Schedule Will Remain Uncertain Until a Sound Business Case Is Established.” August. Accessed February 6, 2012. http://www.gao.gov/assets/300/294326.pdf.

Griffiths, David J. 2005. *Introduction to Quantum Mechanics Second Edition*. USA: Pearson Prentice Hall.

Halperin, Morton H., Priscilla A. Clapp, and Arnold Kanter. 2006. *Bureaucratic Politics and Foreign Policy Second Edition*. Washington, D.C.: Brookings Institution Press.

Halvorson, Todd. 2012. “NASA 'super rocket' on schedule for 2017 launch.” *Florida Today*, May 9. Accessed May 15, 2012. http://www.floridatoday.com/article/20120509/SPACE/305090028/NASA-super-rocket-schedule-2017-launch.

Huber, John D., and Charles R. Shipan. 2006. “Politics, Delegation, and Bureaucracy.” In The Oxford Handbook of Political Economy, edited by Barry R. Weingast and Donald A. Wittman, 256-272. New York: Oxford University Press.

Klamper, Amy. 2010. “Angst Greets Obama Space Plan.” *Space News*, January 29. Accessed February 7, 2012. http://www.spacenews.com/policy/100129-angst-greets-obama-space-plan.html.

Landau, L. D., and E. M. Lifshitz. 1958. *Quantum Mechanics Non-Relativistic Theory*. London, Paris: Pergamon Press Ltd.

Landau, L. D., and E. M. Lifshitz. 1960. *Mechanics*. Oxford, London, New York, Paris: Pergamon Press Ltd.

Launius, Roger D., and Howard E. McCurdy. 1997. “Epilogue: Beyond NASA Exceptionalism.” In Spaceflight and the Myth of Presidential Leadership, edited by Roger D. Launius and Howard E. McCurdy, 221-244. Urbana and Chicago: University of Illinois Press.

Marion, Jerry B., and Stephen T. Thornton. 1995. *Classical Dynamics of Particles and Systems Fourth Edition*. United States of America: Harcourt Brace & Company.

Minkel, JR. 2010. “Is the International Space Station Worth $100 Billion?” *Space.com*, November 1. Accessed on May 16, 2012. http://www.space.com/9435-international-space-station-worth-100-billion.html.

Morgan, Daniel. 2010. “The Future of NASA: Space Policy Issues Facing Congress.” *Congressional Research Service*, July 8. Accessed on February 4, 2012. http://www.fas.org/sgp/crs/space/R41016.pdf.

Morring, Frank. 2007. “COTS Contract Terminated.” *Aviation Week*, September 10. Accessed on February 6, 2012. http://www.aviationweek.com/aw/generic/story.jsp?id=news/rocketplane091007.xml&headline=RpK%27s%20COTS%20Contract%20Terminated%20&channel=space.

NASA Tech Briefs. 2004. “Who's Who at NASA Rear Admiral Craig E. Steidle (USN Ret.)” July. Accessed January 19, 2012. http://nasatechbriefs.com/NEWS/July04/who_0704.html.

National Aeronautics and Space Administration. 2004. "The Vision for Space Exploration." February. Accessed January 19, 2012. http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf.

National Aeronautics and Space Administration. 2006. "NASA Selects Crew and Cargo Transportation to Orbit Partners." August 18. Accessed February 6, 2012. http://www.nasa.gov/home/hqnews/2006/aug/HQ_06295_COTS_phase_1.html.

National Aeronautics and Space Administration. 2008. "NASA Awards Space Station Commercial Resupply Services Contracts." December 23. Accessed February 6, 2012. http://www.nasa.gov/home/hqnews/2008/dec/HQ_C08-069_ISS_Resupply.html.

National Aeronautics and Space Administration. 2009. "Review of U.S. Human Space Flight Plans Committee." June 1. Accessed January 22, 2012. http://www.nasa.gov/offices/hsf/about/charter.html.

National Aeronautics and Space Administration. 2011a. "Selection Statement For Commercial Crew Development Round 2." April 4. Accessed February 7, 2012. http://procurement.ksc.nasa.gov/documents/SelectionStatement-Final_Signed.pdf.

National Aeronautics and Space Administration. 2011b. "CCDev Information." August 17. Accessed February 7, 2012. http://www.nasa.gov/offices/c3po/partners/ccdev_info.html.

Orlando Sentinel. 2008. "NASA has become a transition problem for Obama." December 10. Accessed January 22, 2012. http://blogs.orlandosentinel.com/news_space_thewritestuff/2008/12/nasa-has-become.html.

Powell, Stewart M. 2008. "Houston lawmakers scold Bush for rejecting shuttle funds." *Houston Chronicle*, June 10. Accessed on February 4, 2012. http://www.chron.com/news/nation-world/article/Houston-lawmakers-scold-Bush-for-rejecting-1791073.php.

Quick, Darren. 2011. "NASA announces world's biggest-ever rocket to take man to Mars and beyond." *Gizmag*, September 15. Accessed on May 16, 2012. http://www.gizmag.com/nasa-space-launch-system/19840/.

Reed, Matt. 2012. "Matt Reed: A terrible vote on spaceflight." *Florida Today*, May 11. Accessed on May 15, 2012. http://www.floridatoday.com/article/20120513/COLUMNISTS0207/305130011/Matt-Reed-terrible-vote-spaceflight.

Rogers, Simon. 2010. "Nasa budgets: US spending on space travel since 1958 UPDATED." *The*

Guardian, February 1. Accessed on May 16, 2012. http://www.guardian.co.uk/news/datablog/2010/feb/01/nasa-budgets-us-spending-space-travel.

Rosenberg, Zach. 2011. “ANALYSIS: CCDev walks the fine line.” Flightglobal, October 27. Accessed on May 16, 2012. http://www.flightglobal.com/news/articles/analysis-ccdev-walks-the-fine-line-363994/.

Sabatier, Paul A. 1991. “Toward Better Theories of the Policy Process.” *PS: Political Science and Politics* 24(2):147-156.

Saturno, James V. 2004. “The Congressional Budget Process: A Brief Overview.” *CRS Report for Congress*, January 28. Accessed on July 8, 2012. http://fpc.state.gov/documents/organization/34649.pdf

Seedhouse, Erik. 2009. *Lunar Outpost: The Challenges of Establishing a Human Settlement on the Moon*. Germany and United States: Springer-Science + Business Media and Chichester, UK: Praxis Publishing Ltd.

Shankar, R. 1994. *Principles of Quantum Mechanics Second Edition*. New York: Kluwer Academic/Plenum Publishers.

Smith, Marcia S. 2011. “NASA's Project Constellation and the Future of Human Spaceflight (Historical Information).” *Space and Technology Policy Group, LLC*, May 24. Accessed on February 4, 2012. http://www.spacepolicyonline.com/images/stories/Constellation_Fact_Sheet_May_2011.pdf.

Smith, Marcia S. 2012a. “NASA's FY2012 Budget Request and Final Action.” *Space Technology and Policy Group, LLC*, January 11. Accessed May 15, 2012. http://www.spacepolicyonline.com/pages/images/stories/NASA%27s%20FY2012%20Budget%20Request.pdf.

Smith, Marcia S. 2012b. “NASA's FY2013 Budget Request.” *Space and Technology Policy Group, LLC*, May 13. Accessed on May 15, 2012. http://www.spacepolicyonline.com/pages/images/stories/NASA%20FY2013%20Budget%20Request.pdf.

Stevens, Jacqueline. 2012. “Political Scientists Are Lousy Forecasters.” *The New York Times Sunday Review*, June 23. Accessed June 29, 2012. http://www.nytimes.com/2012/06/24/opinion/sunday/political-scientists-are-lousy-forecasters.html?_r=1.

Taagepera, Rein. 2008. *Making Social Sciences More Scientific: The Need for Predictive Models*. New York: Oxford University Press.

Wall, Mike. 2011. "NASA's Shuttle Program Cost $209 Billion – Was it Worth It?" *Space.com*, July 5. Accessed on May 16, 2012. http://www.space.com/12166-space-shuttle-program-cost-promises-209-billion.html.