Societal Impacts of the Apollo Program

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INTRODUCTION

The civil space program depends on a widespread conviction that our common experience as a state and global community, now and in the future, will be the better for it.[1] One important dimension of this, which is the focus of this study, is that society benefits from a civil space program. The societal benefits are a result of state-directed mobilization of resources and investments in the exploration and development of space.

Civil space exploration brought with it a "lasting gift."[2] This gift is exemplified by the first pictures of Earth from outer space taken by the Apollo 8 astronauts as they circumnavigated the Moon in December of 1968. The famous "Earthrise" photographs allowed humanity to see the Earth as a fragile, life-giving biosphere against the desolation of the cosmos. Since then, Earth observations from space have been critical for better understanding global environmental problems, such as ozone depletion and global climate change, which threaten the habitability of the Earth's biosphere. Earth observations are essential to deal with both mitigation and adaptation strategies to address anthropogenic influences on global environmental change. State-directed investments in civil space programs and projects also resulted in the development of application satellites that play a critical enabling role in modern society. Satellites provide regional and global communication networks, and position, navigation, and timing capabilities that are essential to the functioning of the global economy. Another applied area deals with accurate weather forecasting by satellite that every year saves countless lives through natural disaster mitigation. Additional benefits include crop monitoring and precision farming. This allows for farmers throughout the world to better provide food for their peoples.

As civil space agencies explore and study planets, they learn more about the Earth.[3] Comparative planetology, the study of Earth in comparison to other planets, is instrumental in identifying global environmental problems. For example, NASA scientists trying to understand why the surface temperature of Venus is warm enough to melt lead validated the existence of greenhouse warming and identified its potential devastating effects. Likewise, planetary scientists trying to understand why on Mars materials instantly oxidize due to ultraviolet light penetration from the sun identified what was causing ozone depletion on Earth.

The U.S. civil space program instilled a societal belief in the power of science and technology. The Administrator of the National Aeronautics and Space Administration (NASA) during the 1960s, James E. Webb, forged the concept of a “Space Age America.” This America is one where science and technology is harnessed for peaceful purposes, and for solving social and environmental problems. It is an America where space promotes education in the sciences and engineering. Space Age America is an America with unlimited promise, potential, and hope that humanity can shape a better future for society.

> Here was limitless space, limitless opportunity, limitless challenge… The activist state fulfilled the individual through education, welfare, incentives, new technology… Apollo would open up new realms for the individual in stimulation of the economy and elevation of the human spirit. What was more, the space program… seemed a model for society without limits, an ebullient and liberal technocracy… Space Age America.[4]

The benefits of civil space programs and projects span from ones specific to technology development and innovation, and advances in science and knowledge, to others that entail political, managerial, economic, and educational ones. This study is focused on an examination of these benefits that are defined in this study as societal impacts in relation to NASA’s Apollo program. A number of areas associated with the societal impacts of the Apollo program are critically reviewed and evaluated as to their historical validity.

There areas include, among others: protecting and enhancing the U.S. image abroad as to international prestige and leadership; supporting U.S. national security interests; advancing scientific and technological progress in society; acquiring better knowledge on how to how to plan, manage, and implement great social undertakings that involve the development and application of large-scale technological systems; benefiting industry and the economy through technological development, improving the standard of living; and fostering interest in science and technology related education, and in innovations in educational approaches and curricula development. The investigation of these societal impacts of the Apollo program implies not only an assessment of the immediate and near-term impacts of the Apollo era, defined herein as 1961 to 1972, but also a careful consideration of long-term consequences resulting from intended (first-order) or unintended (second-order) impacts of the Apollo program on society.

The argument put forward and discussed is that the societal impacts (near-term) and consequences (long-term) of the Apollo program are in general of a second-order nature, but in some cases there are first-order influences. Second-order implies unintended impacts and consequences. This is evident in the ways in which Apollo influenced the broader contours of societal culture. Apollo inspired; it fostered an “imagination capital.” This capital was leveraged for political prestige and leadership, federal and industrial investments in research and development (R&D), and as a means to generate interest in education related to the sciences, technology, engineering, and math (STEM) disciplines.

First-order, or direct, impacts and consequences are also present, but are limited to those within the space program itself and to a few specific cases external to the space arena. Apollo influenced how NASA approached management and planning of space programs and projects, and impacts in these areas are present to this day with the implementation of the U.S. Vision for

Space Exploration (VSE or Vision). Outside the space arena, there exist impacts in the areas of city planning, systems architecture, and in the economic and educational areas.

The approach to the historical analysis undertaken in this study is based on a technology assessment of the Apollo program in terms of the societal impacts and consequences. Such an assessment assumes that the benefits of technology outweigh any costs associated with that development. Technology development emanates from both “techne” and “logos.” At the level of techne, meaning the production of something, the skill or the method, there are impacts explored in relation to the managerial and planning method employed by NASA. Logos, on the other hand, means reason. At this level of analysis, the question is one of how such reason was applied to the technical development related to Apollo. Reason in this case concerns the impacts and consequences related to societal culture.

This study is divided into four sections, each of which investigates aspects of Apollo program impacts and consequences. The first part deals with the logos of the “Apollo Paradigm.” An assessment of the political, technological, and exploration dimensions of this paradigm that follows surveys the links between Apollo and societal culture. The second part examines the techne of Apollo as to the management and planning impacts and consequences. This involves the impacts of systems management approaches dealing with the development of these management practices in the U.S. Department of Defense (DOD), NASA’s application of these practices with the Apollo program, and the longer-term impacts to the present on NASA’s approach to administration and management.

In addition to this, several other impacts dealing with management and planning are considered, and entail a discussion of the following: impacts and consequences of systems management practices used with Apollo, namely the Program Evaluation and Review Technique

(PERT); systems engineering applications to city planning; how the best practices and lessons learned from the Apollo program influenced large-scale systems architecture; and the transfer of systems management know-how, applied to Apollo by NASA, to the European space program. The third part deals with economics. Therein a number of impacts and consequences are considered ranging from economic multiplier and productivity impacts, employment, and technology spinoffs as a result of investments made in government sponsored and directed space-related R&D. In the fourth and last part of the study, the educational aspects concerning STEM disciplines are scrutinized.

APOLLO PARADIGM

The Apollo program was a watershed or "turning point" in history.[5] It was an endeavor that demonstrated both the technological and economic prowess of the U.S. and established technological preeminence for the U.S. over rival states, namely the former Soviet Union.[6] Attributable to the Apollo program is a paradigm that instilled a certain belief system. This belief system includes a political ethos, technological ethos, and exploration ethos. It is in this belief system that Apollo set a new standard by which to gauge human achievement– if humans can put a man on the Moon, then they can do all else, both technically and socially.[7]

Political Ethos

As a large-scale national project, Apollo itself represented an important political symbol.[8] "The quintessential large-scale national technological project, Apollo, was far removed from political and social controversies of the time, alienated essentially no one, and… was experienced vicariously by the public."[9] Apollo served a unifying symbol in an otherwise fragmented and pluralistic domestic polity. Internationally, the program was propelled by "prestige,"[10] an intrinsic element in the international relations between states.[11]

Nevertheless, there remains some uncertainty as to how symbolism and prestige affect politics beyond the intangible aspects– that is, in a concrete, tangible way.[12] Given this uncertainty, why then do states pursue large-scale national projects, and more to the point here, why did the U.S. undertake the Apollo program? One answer to this lies in a rational assessment of risks and benefits associated with the endeavor. The political decision-making process that led to Apollo is characterized by such an assessment.[13] The political benefits related to the Cold War and U.S. national interests outweighed the transaction costs– the economic and technical risks associated with Apollo.

A second answer concerns the political influence of technocratic groups that govern the implementation of the space program, and programs such as Apollo; large-scale, state-directed technology development promotes the scientific, professional, and bureaucratic groups.[14] These groups are rooted to the military industrial complex and thus, are often influential in extracting governmental resources for their preferred programs and projects. This is evident with congressional appropriations for the Apollo program, and the justification of those outlays on the basis of benefits to the aforementioned groups. Apollo was justified or rationalized in a number of ways that sought to benefit these groups. This includes: to advance science and technology; to promote and scientific and technical education; to support national security needs; to apply the knowledge gained in managing Apollo; and to benefit industry through technology R&D, innovation, spinoffs, models of efficiency, and stimulation of the economy.[15]

A third answer deals with the particular role of Apollo as a political symbol. In this regard, Apollo is associated with impacts on both national and foreign policies, as well as ideological benefits. The prestige factor of Apollo is an important impact that played a role in the Cold War. The rise of the space age transformed the Cold War into a total war where national and international prestige, and the wherewithal of states to force technological progress, innovation, and modernization became essential political goals.[16] For both the Kennedy and Lyndon B. Johnson U.S. Presidential Administrations, Apollo met vital political needs related to the Cold War confrontation with the former Soviet Union. Space technology was drafted into the cause of national prestige and was embraced as a political panacea. The international image of the U.S., and its standing in science and technology, advanced considerably after the successful completion of the Apollo 11 mission; more people, and states, abroad knew that the U.S. had achieved this endeavor.[17]

Part and parcel of Apollo was the "frontier narrative" attached to the program. This narrative, which is associated with historical ideas rooted in exploring, conquering, exploiting, and closing the frontier, and exemplified in U.S. history by the westward expansion and ideology of "manifest destiny,"[18] became a way to understand the space program for the public, while reaffirming U.S. values and institutions during the uncertain years and challenges of the Cold War.[19] The launching of Sputnik 1 by the Soviet Union in 1957 highlighted these challenges, and this event represents what historians call a "turning point" or watershed event that led to societal sea change.[20]

Sputnik 1 presented both national and international challenges to the U.S. Former U.S. President Johnson stated that "one can predict with confidence that failure to master space means being second-best in the crucial arena of our Cold War world. In the eyes of the world, first in space means first… second in space is second in everything."[21] Nationally, Sputnik challenged the idea of limited government investments in technology R&D, and questioned the superiority of U.S. institutions and values, such as a democratic system of governance, bureaucracy tempered by public and political accountability, political freedoms, and open inquiry and dissemination of knowledge. Internationally, Sputnik 1 suggested Soviet strategic parity with the U.S., questioned the military assumptions upon which the “free word” was based, and undermined U.S. world prestige and leadership. Sputnik signaled that U.S. sociopolitical and socioeconomic systems where anachronistic in a Space Age characterized by explosive technological advance.

> Sputnik posed a great challenge… As a foreign threat with military overtones, it was clearly the government’s business. As a blow to U.S. credibility, it seemed to demand a response in kind. As a technocratic accomplishment, involving the integration of science and engineering under the aegis of the state, it called into question the assumptions behind U.S. military, economic, and educational policy– every means by which the mobilization of brainpower is achieved.[22]

These challenges resulted in a number of impacts within the scope of this study. First, it fostered a sea change in the role of government regarding technology R&D and utilization. The ideas encapsulated with “Space Age America” discussed in the next section are one aspect of this. The other is entailed in the economic themes related to technology development, innovation, applications, and utilization. This discussion takes place in the economic part of this study. Second, it led to the creation of NASA in 1958, and played a role that led to support and implementation of the Apollo program. Apollo became an “implementation model” to be emulated. Through adaptation of planning and management methods used by the DOD in ballistic missile development to the context of Apollo, NASA forged systems and program management models that impacted administration and management of NASA programs and projects other than Apollo. These aspects are discussed herein as well. Third, Sputnik 1 ushered in educational reforms that addressed issues with STEM related education. These reforms and the links to the impacts of Apollo on education in this regard are reviewed in this study.

Technological Ethos

The technological ethos of the Apollo program is no better characterized than by the Space Age America theme advanced by the leadership at NASA, and supported by the U.S. Presidents and Congresses of the Apollo era through the Johnson Administration. Space Age America was about how to undertake large-scale endeavors of public value through technocratic governmental agencies and large budgetary outlays; a model for society with unlimited promise, potential, and hope that we can shape a better future– a liberal technocracy.[23] This model for society is based on the idea of the "Moon-Ghetto" metaphor put forward in the Apollo era; if we can go the Moon, then we can use the same know-how in organizing human affairs to solve societal problems, and to advance societal goals. The historical argument was that the Apollo program instilled a belief, an ethos, in harnessing the power of science and technology for solving social and environmental problems, for fostering education in STEM disciplines, and for advancing economic prosperity. It is these ideas that served as some of the philosophical underpinnings of President Johnson's "Great Society" agenda and programs.

One of NASA's missions was to use science and technology emanating from the space program to strengthen the economic and educational interests of the U.S. Webb, NASA Administrator from 1961 to 1968, sought to create this Space Age America model of society.[24] This model suggested that the technocracy and bureaucracy needed to undertake Apollo can also be directed to fulfill societal ends, like stimulation of the economy, education, and new technology harnessed to solve societal problems. Impacts in the areas of technology, economics, and education are assessed in this study.

Through Apollo, space became linked to the organization vitality of the state and to modernization, especially in terms of state-sponsored and state-directed technological R&D. Webb contended that Apollo was more a management exercise than anything else, and that the technological challenge, while sophisticated and impressive, was largely within grasp.[25] More difficult than this was ensuring that those technological skills were properly managed and used, and in this use there are applications in new thought processes concerning information and knowledge, which serve as a powerful engine of progress relevant to other social goals.

Another impact of the technological ethos is that it influences the level of public confidence in the ability of government to perform; the Apollo program, through the planning and management skills applied therein with successful results, helped to create a culture of competence engendering high levels of public confidence in the U.S. federal government.[26] Trust in government among the public was more than 70% with the start of the Apollo program in 1961, and within the 55% to 60% range during the manned Apollo missions.[27]

The level of public confidence in NASA as a federal agency as to what the government can do competently is sustained as a longer-term consequence. From the flight of the first Space Shuttle in 1981 to 1994, to illustrate, 60% to 80% of the public approved of the civilian space effort.[28] In 1997, one survey of pubic attitudes toward the federal government found that 85% viewed the government as very successful in working toward the goal of space exploration.[29] This was the highest favorable rating of all the categories considered, including: national defense, economic growth, environment, health and safety issues, civil rights, education, crime, poverty, moral value, illegal immigration, and reducing drug abuse. Even though the public management aspects of NASA are often subject to criticism by the U.S. Congress, the public continue to believe that NASA is doing a “great job” as a federal agency.[30] Furthermore, the aura of competence surrounding Apollo proved that the U.S. possessed the skill, technology, and wealth to complete voyages to space; it is this sense of accomplishment, along with governmental competence, that Apollo and NASA symbolized. This helped maintain support for a human spaceflight program even as national leaders debated and questioned the goals of the programs (i.e., Space Shuttle and International Space Station programs).[31]

Exploration Ethos

There is the argument put forward by those involved in the civil space program, among them the late Carl Sagan, that tangible, pragmatic benefits and impacts are inadequate to sustain political and popular support for human space exploration. Rather, an intangible exploration ethos is needed. The primary justification of space exploration lies in the imperatives of human nature.

> …we are the kind of species that needs a frontier– for fundamental biological reasons. Every time humanity stretches itself and turns a new corner, it receives a jolt of productive vitality that can carry it for centuries. There is a new world next door. And, we know how to get there.[32]

The exploration ethos of the Apollo era encapsulates this intangible factor. One significant impact of this ethos is how Apollo forced the people of the world to view planet Earth in a new way.[33] One of the Apollo 8 astronauts that circumnavigated the Moon, the first humans exposed to images of the “Earthrise” over the lunar horizon, said that “we came all this way to explore the Moon, and the most important thing is that we discovered the Earth.”[34] The Earthrise images have had profound implications that go well beyond the space area– a vision of the planet Earth as a holistic natural and social system.

The Earthrise images offer an environmental perspective that played a role in spawning the modern environmental movement and Earth system sciences. The environmental movement was galvanized in part by this new perception of the planet, and the need to protect it and the life that it supports. Earthrise as harbinger of Earth observations enabled scientists to study the Earth's environmental system in a systemic, holistic fashion. As a social system, Earthrise provides humanity with a new perspective with implications for states and international relations. Apollo set into place images that reflect the globalization that exists today. Sagan stated that gift of Apollo to humanity, justified by the Cold War and the nuclear arms race, is the stunning transnational vision of Earthrise, and that global cooperation is the key to humanity's survival.[35]

Associated as well with Earthrise are the social and spiritual impacts on the space explorers themselves.[36] The Apollo astronauts represent one set of these space explorers. One work in this area compiled and assessed the views of number of space explorers, astronauts and cosmonauts, and found that their space experiences are represented by an "Overview Effect."[37] More specifically, the views of the space explorers as they related to the Overview Effect cover the following themes: an abiding concern and passion for the well-being of the Earth relating to the themes of globalization, transnationalism, global cooperation; recognized need for a stewardship perspective and a global participatory management of the planet that is addressed within environmentalism; and an understanding, or awareness, that everything is interconnected and interrelated concerning holistic and systemic views and thinking.

Related to the exploration ethos, and particularly the Apollo astronauts, is Apollo as an iconographic symbol. The societal impact of this is no better exemplified than by Music Television's use of an Apollo image. Figure 1 below shows this image. This image suggests that the mythology of the astronaut in American culture established a representation of the "best" that the U.S. has to offer the world. This reflects back to the prestige and competence factors discussed earlier.

Figure 1. Music Television's Iconic "Astronaut." Source: Music Televsion.

Historians have made the point that the Apollo astronauts served as surrogates for the society that they represented. This impacted the way in which humanity views its future.

> …the astronauts represented a powerful generational theme, the young, powerful warrior guided by an older, prescient, and often mystical leader or leaders who envision a wonderful future for the nation. In this context, the astronaut is making safe the way for the civilization to go forward, to progress toward a utopian future elsewhere in the cosmos.[38]

Longer-Term Consequences of the Apollo Paradigm

The conditions of the political system in the 1960s supported the political, technological, and exploration worldviews of the Apollo Paradigm. Interestingly, the beginnings of the demise of the paradigm are rooted in the management difficulties faced by Webb after 1965, which culminated in the 1967 Apollo launch pad fire that killed three Apollo astronauts, and following that Webb's resignation as NASA's Administrator in 1968.

By the end of the 1960s, the worldviews of the paradigm were no longer valid in changed societal circumstances.[39] A number of factors precipitated the demise of this paradigm. These factors entail: the counter-culture movement in the U.S. of the 1960s; the development and rise of the environmental movement; the energy crisis of the 1970s; the economic malaise in the U.S. exemplified by high inflation in the 1970s; a conservative reaction against big government that Space Age America represented; sustained use of satellite systems for Earth observations and robotic probes for planetary and cosmological exploration; and factors regarding the advent of virtual reality systems, and the privatization and downsizing of government activities.

The post-Apollo era was earmarked by a decline in support for human space exploration as measured by appropriated dollars from the federal government. Fulfilling the challenge of placing humans on the Moon and a foreign policy of détente, that ended the space race and relaxed Cold War tensions between the U.S. and the former Soviet Union, led to an emphasis on the building of a human spaceflight infrastructure. To this end, economics and enabling technologies were critical supporting variables. Human spaceflight was wedded to space utilization and a "mission to infrastructure" in low Earth orbit (LEO). This course of action is exemplified by both the U.S. and Soviet/Russian space programs, and involved projects like Salyut and Mir Space Stations, Apollo-Soyuz, Skylab, Space Shuttle, Shuttle-Mir, and the International Space Station (ISS) program of today.

This implied that Apollo's exploration belief system gave way to a "post-Apollo" utilitarian belief where other social and political concerns dominated space policy in the U.S. In short, U.S. space policy became ancillary policy.[40] At the time, science and technology became increasingly viewed as “autonomous” forces that could be not be controlled or guided to the benefit of society as thought by the advocates of Space Age America. This was compounded by the fact that the application of technology did not necessarily solve all social ills, was very often found to be destructive to the environment, and was used for military purposes, like the war in Vietnam.

From a utilitarian outlook, space offered a platform for dealing with Earthly priorities. Rather than advance prestige and leadership through human space exploration achievements, the U.S. sought to lead in practical scientific and technological capabilities with tangible economic returns. Even though the rhetoric and metaphors in support of “Apollo-like” political and exploration beliefs resurfaced during the 1980s, concrete political support, like increased funding, was absent. Concomitantly, the theme of space utilization was advanced– at the expense of exploration– by supporting commercialization of space activities.

As a result, presidential and congressional politics were incongruous with sustaining the human space exploration efforts begun with Apollo. NASA also encountered organizational changes in its cultural make-up that led to planning problems and errors of judgment, such as the decision to launch the Space Shuttle Challenger in January of 1986. By way of illustration, NASA went from a R&D culture during Apollo to an operational one afterwards; from a frontier mentality and the propensity to assume risk to a utilitarian (applications and operations) outlook and the propensity to avoid risk; and from an engineering culture to a more bureaucratic, managerial one.[41]

Since the end of the Apollo era, a fundamental concern of the space community is the search for justifications that entail impacts or benefits to support human space exploration missions. This spawned a number of studies and reports in the U.S. NASA’s post-Apollo plans called for resources to implement the development of a space shuttle, orbital space station, nuclear space tug, human-tended lunar base, and human expeditions to Mars.[42] In the 1980s and 1990s, a series of reports and initiatives for human space exploration missions were proposed.[43] These reports justified future space program scenarios on the basis of national benefits like prestige, leadership, technological development and innovation, and economic growth.

For example, the Space Exploration Initiative was justified on a number of factors that encompassed: national prestige; advancing science education; developing technologies; commercializing space; and strengthening the economy.[44] The *Ride Report* (1987) provided a systematic analysis of the civilian space program to show how the U.S. lost its leadership position in space vis-à-vis the Soviet Union, principally as it related to maintaining a permanent human presence in LEO.[45] On this basis, a space strategic development plan for the 21st century is developed by Ride based on restoring American leadership status. This requires that the U.S. possess capabilities that enable it to act independently and impressively in the space environment when and where it chooses.

NASA's strategic planning process[46] focused on developing its enterprises to meet the goals of various governmental (president and congress) and domestic public constituencies with the benefactors being policy makers, science communities, aeronautics and aerospace industries, other governmental agencies, public sector, and academic communities within the U.S. A number of different strategic plans were formulated beginning in 1994, with the most recent ones being issued in 2005 and 2006.[47]

The 2005 and 2006 plans emerged in response to VSE. These plans put into place a "one NASA vision" that emphasized R&D and an exploration ethos reminiscent of the Apollo era. The 2006 plan is tailored to specify how NASA will implement the goals of the Vision. In the area of human spaceflight, this entails near-term goals of Space Shuttle return-to-flight and completion of ISS, and longer-term goals of a lunar return program to enable lunar base development and human missions to Mars. Of note in relation to the Apollo impacts theme of this study, is that the strategic planning process is indicative of centralized control on the planning and development of NASA programs and projects, akin to systems management practices used by NASA with Apollo.[48]

On one hand, there are negative impacts surrounding the demise of the Apollo Paradigm in that the premises of the political, technological, and exploration ethos systems were either not sustained, or left unfulfilled, in terms of the promises offered. Yet, the paradigm sustained an impact on the civil space program in the U.S. The ideas rooted in the paradigm led to consequences in how the space program is rationalized and justified, very often on the basis of societal impacts as the aforementioned examples suggest, and on the planning and management approaches and practices dealing with NASA's programs and projects.

MANAGEMENT AND PLANNING IMPACTS AND CONSEQUENCES

The historical claim concerning the management and planning impacts and consequences of Apollo is that one of the most valuable impacts of the Apollo program was human, rather than technological; better knowledge of how to plan, manage, and implement great social undertakings that involve the development and application of large-scale technological systems.[49] It is this claim that served as the basis for the Space Age America theme and the technological ethos of the Apollo Paradigm that were both discussed earlier. This part of the study first explores how NASA adapted management and planning practices used by DOD, and then assesses how NASA's use of these practices led to societal impacts.

United States Department of Defense as a Model

The U.S. space program created an unprecedented demand for managers with both technical and administrative competence both in industry and government. In meeting this demand, an enhanced an understating of the application of management to the technology development process was realized. This societal impact entails: matrix-type communications; environment of managing and performing with high-levels of reliability, performance, and accountability; consistent involvement of top-managers in the technology development process; systems management approaches; and new uses of contracting methods (e.g., incentive contracting and total package procurement). It is acknowledged and documented in the literature that many of the management models used for civil space were developed by the U.S. military, particularly in the development of ballistic missile programs, and then launch vehicles for accessing space. In fact, many of the NASA systems management methods were incorporated into the Agency from DOD.

Innovation on NASA's part is shown in how NASA management implemented DOD "best-practices" into a civilian program. NASA was able to integrate effective management controls in the Apollo program. More specifically, phased planning and configuration management techniques, used successfully by the U.S. military in ballistic missile development programs, were integrated into the management of Apollo. DOD's development and application of phased planning for the Titan III program, which entailed defining the project's objectives, costs, and schedules in a preliminary design phase, became a DOD standard by the mid-1960s that NASA adopted in 1967.[50] As early as 1961, the U.S. Air Force Ballistic Missile Division developed configuration management.[51] Configuration management, which is further explained in the section below on "Apollo Management as a Model for the Vision," is a managerial technique to control design and technical changes, and to link that to cost predictions and cost control. Of relevance here, is that this management technique was independently created at NASA and the Jet Propulsion Laboratory (JPL). The technique emerged as a primary contractor control process, enhanced the reliability of systems, and became a standard process throughout the aerospace industry.[52]

Such systems management approaches were "secrets of success" in enabling NASA to meet its lunar goal of placing humans on the Moon and returning them to Earth safely during the decade of the 1960s.[53] The incorporation of system-related approaches and the impacts on NASA are discussed in the next section dealing with impacts of the Apollo model for management. PERT, as a further illustration of a specific systems management approach with impacts, is considered next.

PERT– Program Evaluation and Review Technique

PERT is a model for project management invented by U.S. Navy Special Projects Office in 1958 as part of the Polaris mobile submarine-launched ballistic missile project.[54] This project was a direct response to the "Sputnik crisis." PERT is a method for analyzing the tasks involved in completing a given project, principally the time needed to complete each task and to complete the total project. The method was applied to simplify the planning and scheduling of large-scale, complex technical projects.

NASA incorporated PERT and applied it as system management practice in dealing with Saturn launch vehicle development.[55] During the early phases of the Saturn program, Marshall Space Flight Center management regarded PERT as a very successful effort, and as the best source of information available on the status of hardware programs. Despite this, the PERT network was phased out due to cost considerations by the time of the launch of the first Saturn vehicle in 1967.

This indicates that the overall impacts of PERT on the Apollo program are open to question. In many cases, PERT was introduced too late to make much of an impact on funding and schedules. The value of PERT was seen more as a preliminary planning tool and coincidental to manage the on-going complexity within the Apollo program.

> The only way you ever got PERT really implemented was to go around and ask the guy who was supposed to be doing it where he stood on his PERT program, and you could usually find that he had his own program in his desk drawer. PERT was the thing he was talking to you about, but whether it actually meshed with what was going on… was in some instances coincidental.[56]

In fact, as more complexity emerged within the systems used for Apollo, PERT became difficult and costly to use, lagged in real-time usefulness, and was subject to manipulation to avoid exposure of cost, schedule, and technical problems.[57]

Apollo Management as a Model for the Vision

NASA leaders acquired and organized unprecedented resources to accomplish the tasks of Apollo. In many ways, Apollo was just as great a management feat as a technical one. The management models and methods developed and used for Apollo successfully met the enormously difficult engineering, technological, and organizational integration requirements of the Apollo program.[58] Public management of Apollo provided better knowledge concerning how to plan, manage, and implement great social undertakings that involve the development and application of large-scale technological systems. NASA employed program management concepts that centralized authority and emphasized systems engineering. Systems management approaches were critical to Apollo's success. Understanding the management of complex technical structures for the successful completion of a heterogeneous task was a critical outgrowth of the Apollo effort.[59]

A comprehensive assessment of Apollo program management identified a number of dynamic and evolutionary management structures and process within an environment of program controls.[60] This encompasses: assuring the development of cohesive and flexible patterns of management in both NASA and industry; management visibility at all levels based on detailed monitoring and auditing systems that allowed the flow of information both vertically and horizontally; successful correlation and definition of multiple program interfaces in both NASA and industry; establishment of a real-time, flexible management reporting system that balanced freedom of innovation with reporting and control discipline for accomplishment of program objectives; and development of a balance between NASA's in-house capability and industrial capability.

One important theme that emerges is that program management of Apollo combined centralized planning and a hierarchical organization with decentralized and flexible technology development processes. Centralized bureaucratic processes overlaid technical accountability systems characterized by project management and systems engineering methods. This allowed for organizational accountability. NASA integrated the relatively autonomous technical cultures within its field centers through a centralized management structure that applied the formal controls of systems and configuration management.

A specific way that control was put into place was by imposing an organizational structure on the technical work teams. In relation to the technical engineering teams working on Apollo, engineers initially coordinated changes among themselves in committees. With the integration of systems management into NASA, managers inserted themselves into the engineering teams to understand what was happening, and soon required the engineers to give cost and schedule estimates for these changes.[61] An important method to control the development of technology, in light of the rapid technological innovation and change, was that of configuration management. This method provided an essential link between engineering coordination and centralized organizational control. Even though program controls used for Apollo permitted NASA to have centralized management at Headquarters, the information received there was then distributed to the NASA centers; managers at Headquarters availed themselves of the technical competence and knowledge at the centers, and the project mangers at the centers were kept current on Headquarter activities.[62]

Organizational management practices during Apollo represented a continuing process of adjustment and adaptation to the dynamics of change internal and external to NASA. Flexible management processes were essential to success.[63] NASA's organizational scheme was one of simultaneous centralization and decentralization, a "desired disequilibrium."[64] Organizational flexibility was an essential part NASA's managerial ethos. Webb realized that NASA could not be governed solely by classical principles of "scientific management" that sought to institutionalize stability and order with centralized and hierarchical organizational structures. In order to manage large-scale technological systems, and allow for technological innovation, Webb recognized that organizations needed to retain flexible, decentralized management patterns and processes; Webb balanced scientific management based on control with a decentralized technical culture at NASA.

Simultaneous centralization and decentralization was advanced by the "triad" decision-making structure that Webb established.[65] Webb shared top-level decision-making at NASA with two administrators, Hugh L. Dryden.[66] and Robert C. Seamans.[67] Webb met the pressures of political accountability being responsive to the concerns of the president and congress; Dryden ensured technical authority; and Seamans functioned as a bureaucratic manager through the application of systems management approaches at the Agency. The triad successfully mediated among political pressures of accountability, and the drive for high-performance and high-reliability.

The near-term impacts of the Apollo management model lie with the direct application of the systems management approaches to the Space Shuttle and ISS programs. These impacts, however, were negative ones. With the end of Apollo, systems approaches were less effective. This is due to the fact that Apollo was characterized by a “closed” systems approach in the sense that the program was largely shielded from external political changes.[68] Many of the management problems attributable to the Space Shuttle and ISS are a result of how these programs are continuously managed with political accountability in mind, and within an environment of political change. The operational view of the technological systems further constrained the direct utility of systems approaches used with Apollo. The systems approaches used for Apollo were optimal for the experimental and developmental nature of the technology for that program. These systems approaches were not optimally adaptable to the management processes with the Space Shuttle and ISS that often emphasized operational and economic, cost control imperatives.

Longer-term consequences exist to the present and are most notable with how NASA is implementing VSE. With this Vision, the NASA Administrator used the phrase that the exploration systems architecture[69] directed at the development of lunar transportation system is “Apollo on steroids.”[70] The idea is that NASA is looking at Apollo as a technical model on how to get back to the Moon. There is also similar analogy in the management area. In making this analogy, the organizational management idea of “desired disequilibrium” that NASA Administrator Webb put forward to describe a need for healthy tension between centralized aspects of management, such as control over cost and schedule, and decentralized aspects of management, such as ensuring that authority over technical competence and engineering is at the NASA field centers, is what NASA is emulating today.

> Webb once characterized his role during the Apollo program in the following way: “The process of management that of fusing at many levels a large number of forces, some countervailing, into a cohesive, but essentially unstable whole, and keeping it the desired direction.” This… perspective serves me well today.[71]
>
> …we are looking for an appropriate level of tension, an appropriate level of constructive disagreement, or that desired disequilibrium that Webb referred to, that unfortunately after Apollo was subordinated to program management authority. We want to go to a meeting and to have the engineering director upset with the project manager for not following one of his recommendations. We have not had enough healthy tension in the Agency. That tension should exist all the way to the top of the management chain.[72]

The establishment of *the* Associate Administrator position at NASA, along with the Deputy Administrator position, put into place a leadership at NASA that is based on the triad model that Webb used during the Apollo era. NASA examined Webb’s management model as NASA’s most successful era and decided to emulate that. It is the same basic type of model in terms of a balance of power between political, institutional or organizational, and technical aspects of management. Figure 2 below shows this relationship.

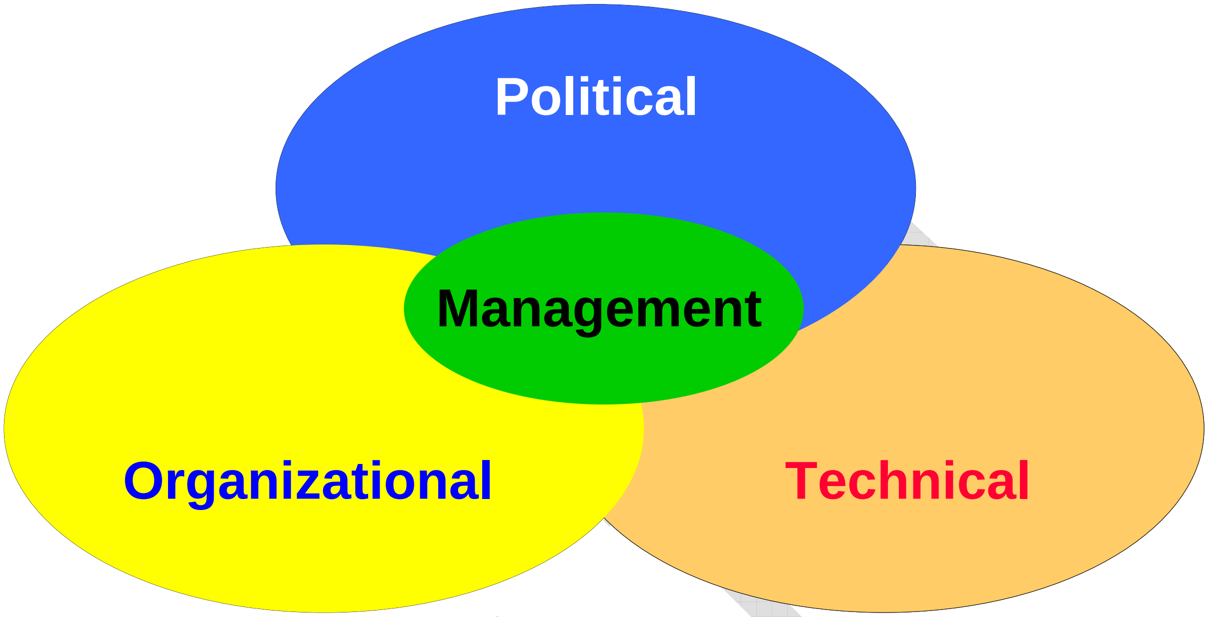

Figure 2. Public Management Dynamics of NASA. Source: author.

There are three key organizational changes at NASA that reflect this balance of power. These changes represent the means by which NASA today is emulating systems management controls that were applied with the Apollo program. The key changes are discussed next, and include: separation of institutional and programmatic managerial authority; independent technical authority; and integrated financial management– NASA's Integrated Enterprise Management Program.[73]

Separation of Institutional and Programmatic Managerial Authority

Centralization of management and technical authority is directed to mitigate decentralized aspects of management that foster the consolidation of managerial power and authority at each NASA field center.[74] NASA is institutionalizing a separation of programmatic authority, which deals with the organizational aspects of management that involves control over budgets and schedules, from institutional authority that concerns technical aspects of management–engineering, safety, and mission assurance. Prior to this, NASA was organized on the basis of a lead-center structure; institutional program offices at NASA were associated with specific mission directorates at NASA. The mission directorate, that manages human spaceflight, had institutional authority over NASA's Marshall Space Flight Center, Kennedy Space Center, Johnson Space Center, and Stennis Space Center; and the directorate that manages the science and robotics, had institutional authority over JPL and the Goddard Space Flight Center. Throughout NASA there was a blending of institutional and programmatic responsibility; NASA center directors were in the chain-of-command for both institutional and program authority.

> You had institutional authority flowing from associate administrators to center directors, and then over to program and project managers. When that exists, you have center directors with a tremendous amount of power because they have institutional authority as well as program and project management authority. In other words, the center directors can directly control the budgets, schedules, and technical management of the programs and projects.[75]

The current reorganization of public management at NASA, on the basis of separation of institutional and programmatic authority, involves the centralized control of center directors at the NASA field centers, independent from the centralized control of the NASA mission directorates and associate administrators that manage those directorates. Within this organizational scheme, the program chain-of-command runs from a centralized manager at

NASA Headquarters, *the* Associate Administrator,[76] through associate administrators that manage the mission directorates, to program managers at the field centers. The center directors are not in this chain-of-command. The institutional chain-of-command runs from *the* Associate Administrator to the field center directors, and to directors of engineering and safety, and mission assurance at the centers, people on the institutional side of management. With this organizational structure, center directors are not in the accountability chain for program or project success. The center directors are accountable for providing appropriate support for the programs and projects to be successful, such as adequate technical and engineering expertise, but that is an institutional responsibility and not a cost and schedule responsibility.

> This does several things for you. It separates institutional authority from programmatic authority so that you can a have an appropriate and clean technical chain-of-command separated from the programmatic chain-of-command; it keeps the center directors from controlling budgets for program and project management; and it establishes a clear chain of accountability down the program side. All factors combined together, can give you what you want, which is good technical execution in the field centers, appropriate centralized controls from NASA Headquarters, and a reasonable decentralization for the engineering.[77]

Independent Technical Authority

An Independent Technical Authority[78] was instituted at NASA in January 2005. The intent of Technical Authority is to put into place a centralized managerial model that will bring technical accountability and competence to be considered as important as other issues in the management process. The authority represents a centralized approach to ensure that all management issues involving technical requirements– technical policies, specifications, standards, processes, and procedures– are considered independently from organizational and political factors in the management process.[79]

Before the Independent Technical Authority, managerial authority for technical issues existed within a decentralized framework, either at the NASA field centers or advisory to NASA as with the Aerospace Safety Advisory Panel.[80] The decentralized approach led to a situation where managing to cost, schedule, and performance goals were traded-off with managing to high-reliability and safety. This was identified as one of the underlying causes for the Space Shuttle Challenger and Columbia accidents.[81]

The Independent Technical Authority rests with the Office of the Chief Engineer at NASA Headquarters and exists independently of program and project managers. The Chief Engineer is given the power to establish, approve, and maintain technical requirements on all programs and projects. This includes the power to make program and project managers comply with the technical requirements– a means to institute technical accountability and technical competence. It provides an organizational mechanism whereby the engineering workforce can make sure that managers are forced to address anomalies in the technical systems identified by the engineers.

The implementation of the Technical Authority takes place through a technical warrant holder system supported by the Office of the Chief Engineer at NASA Headquarters. Albeit Chief Engineers at the field center level are assigned as warrant holders, the engineering decisions are made independently from other managerial concerns. This is facilitated by organizational separation of institutional authority from programmatic authority that was explained earlier.

> In the way that we have rewired the organization, so that the institutional and programmatic areas are separated all the way to the top of the Agency, you have chance to make the Technical Authority not some kind of an appliqué or wire around, but an organic feature of the organization. As an organic feature, you now have engineering institutionally and organizationally separated from program and project authority. The

> technical requirements of any program are then owned by the engineering institution that then supports program and project development.[82]

Integrated Financial Management

After Apollo, a lack of disciplined cost-estimating at NASA hindered effective public management. NASA lacked centralized controls over costs, and there is evidence of NASA's inability to collect, maintain, and report the full costs of its programs and projects. One credible study assessed, on the basis of budget data provided by NASA, that average growth, in the costs of a set of 72 programs executed by NASA since 1977, averaged 45%, excluding the effects of inflation.[83] In exacerbation of these cost management problems, NASA performed an internal audit of the ISS program in 2002 and informed the U.S. President and Congress of an expected $4.8 billion cost overrun. All this led to the conclusion that the financial system used by NASA was not a credible one. In response, NASA put into place an integrated financial management program, now called the Integrated Enterprise Management Program, beginning in fiscal year 2004.[84]

The Management Program is another example of centralization of the management process. At issue, is the centralized control over managing to cost and schedule. One key part of the program is full-cost accounting.[85] Organizational accountability is provided through a centralized Institutional Committee and Program Management Committee at NASA Headquarters.[86] This accountability system ensures that full-costs– all direct costs, service costs, and general and administrative costs– are accounted for at the program level. The management process is then shifted to realize an organizational strategic objective per NASA's strategic planning process.

The fundamental challenge before NASA is to convert from disparate financial systems at each field center to one integrated financial system that works across the Agency. The implementation of an integrated financial system allows NASA to align budget structures with project work breakdown structures from the very top of the Agency to the bottom at the field centers. With fiscal year 2006, NASA is implementing standardized cost elements in projects. The standardization of key elements dealing with project development, like engineering, safety and mission assurance, and spacecraft components, facilitates a more reliable cost-estimating model for the management of cost and schedule.

Apollo, Culture, and Organizational Change

Culture frames the context for public management in terms of norms of behavior as in how organizations do things; culture shapes how an organization interacts with technical and political variables, and determines task-related behavior.[87] The primary cultures of relevance to NASA are competency and control. The competency culture is decentralized and is characterized by a number of traits, including: decentralized and informal, redundant patterns of communication and authority based on independent engineering and automatic responsibility for critical review and oversight of technical issues; an exploration ethos and emphasis on R&D directed at high-performance outcomes; risk-taking aimed to avoid an error of launching an unreliable spacecraft; and culture of the engineer and associated value on in-house technical capacity for systems integration, and contractor oversight and monitoring.[88] Competency is practiced through an emphasis on technical accountability, project and team-based management approaches, and systems engineering. The “original technical culture” that NASA inherited from its predecessor organizations, the NASA field centers today, is one of competency.

These organizations and their associated cultures are comprised of the U.S. National Advisory Committee for Aeronautics and that organization's experience with engineering by technical committee and peer-review processes, the U.S. Army Ballistic Missile Agency and in-house technical development, the U.S. Navy's Research and Ordinance Labs with a focus on in-house engineering and R&D, and the U.S. Army and the project management methods the Army pioneered with both missile and rocket development. During Apollo, 80% of NASA's technical workforce had corporate memory of these organizations, and the original technical culture largely set the context for how the centers and the Agency worked.[89]

Control is a culture that permeated NASA from its ties to the U.S. Air Force (USAF), and program and project management systems in industry. The control culture is a centralized one characterized by the following: hierarchical patterns of communication based an centralized bureaucratic processes and procedures for program and project control through documentation and standard operating procedures (SOPs); an operational and utilization ethos rooted in the notions of efficiency, and applications and benefits of space technology; risk-aversion to avoid on error of not launching a reliable spacecraft; and culture of the bureaucratic that values contracting-out and the model of corporate power and control.[90] Control is practiced through systems approaches to management, and related practices of configuration management.[91]

The cultural traits related to competency and control shifted in NASA's history. In the Apollo era, the "original technical culture" was predominant. As Apollo moved to fruition, the original technical culture changed as cultural aspects of control took hold. This dynamic of cultural change is largely due to two factors. First, are the budgetary contraction and the associated political pressures that NASA faced after Apollo. This resulted in managing to economic considerations and notions of efficiency. This also led to workforce changes at NASA that emphasized a management culture, with reductions in engineers and subsequently, in-house technical expertise.[92] The three key organizational changes examined earlier– separation of institutional and programmatic authority, independent technical authority, and integrated financial management– represent an attempt to put into place cultural and organizational management changes at NASA that are more reflective of the cultural traits and management practices that existed during the Apollo era. Apollo became a model to emulate at NASA.

Systems Approaches to City Planning

The development of systems management approaches in the space program enables systemic design, development, and implementation of large-scale, complex systems. Systems management approaches were viewed to have applications to socioeconomic problems dealing with urban and city planning and administration.[93] The evidence suggests that impacts are at the level of ideas and potential applications (second-order), and not in terms of direct impacts that can be attributed to systems management practices applied with the Apollo program.

A systems approach facilitates a number of aspects that apply to these areas. This ranges from: definition and detailed description of system boundaries; functional descriptions of the system in terms of component subsystems and their operational interactions; determination of objectives and criteria for optimal system performance; examination of alternative configurations of system elements that approximate optimal system performance; the determination of the consequences of each configuration as to feasibility, adaptability, and cost effectiveness; and objective presentation of alternatives to support decision-making. These aspects of a systems approach can allow for the analysis of urban a city planning problems in an integrated fashion.[94]

In the 1960s, NASA and those in the Aerospace community put forward this argument and tried to link the concept of Space Age management as applied with Apollo to city administration. The basic idea is that both NASA and city institutions require appropriate organizational architectures for successful problem-solving within complex environments that entail organized, disciplined, and highly structured human activities oriented to numerically stable goals.[95] Examples of this in the city setting deal with communication, power, transportation services, pollution and crime controls, and waste management.[96]

Managerial Heuristics and Systems Architecture

Systems architecture is related to systems management approaches of the 1950s that were formulated to help with the development of ballistic missile programs in the U.S. The first standard for systems architecture was developed in the USAF. As discussed earlier, NASA's incorporation and adoption of systems management practices, pioneered in part by the USAF, played a critical role in the managerial success of Apollo. Systems architecture is the art and science of creating and building large-scale, complex systems, and then developing system-level solutions.[97] System architects concentrate on initial system definition and design in making use of systems engineering specialties to develop satisfactory and feasible system concepts. The architectural approach is needed most as systems become more complex and multidisciplinary.

The influence of best practices and lessons learned from the management and planning of the Apollo program can be thought of as managerial heuristics. Heuristics are simple, efficient rules of thumb proposed to explain how people make decisions, come to judgments and solve problems, typically when facing complex problems or incomplete information. The managerial heuristics derived from the Apollo program impacted the practice of systems architecture.

The Apollo program generated a number of important heuristic perspectives about complex, large-scale sociotechnical civil programs, and represents an exemplar case study, for the application and formulation of systems architecturing, in terms of both what to do and what no to do.[98] For example, a heuristic that grew out of Apollo is that a system is successful when the natural intersection of technology, politics, and economics is found. Apollo was a successful program because of the significant support across these elements. Purpose orientation is another key element in modern systems architecting; a clear and useful purpose is vital for a successful system. Apollo's purpose and prioritization to put humans on the Moon by the end of the decade of the 1960s, to demonstrate technological and political superiority over the former Soviet Union, represents purpose orientation.

Systems architecture begins with, and is responsible for maintaining the integrity of the system's purpose. A system will develop and evolve much more efficiently if there are stable intermediate forms, than if there are not. As the purpose of a system evolves, stable, intermediate forms allow the system's functionality to be altered. When purpose changes, the whole program does not need to be terminated, but rather just fall back to the last stable form and refocus.

As this relates to Apollo, the decision to bypass an orbiting Earth infrastructure, such as a space station element, for supporting exploration of the Moon, and choosing instead a direct lunar mission design (lunar orbiter rendezvous or LOR) drove infrastructure and technical requirements that were less reusable when NASA's post-Apollo mission changed.[99] In connection to this consequence, is the realization that the best engineering solutions are not necessarily the best political solutions. There were engineers that wanted to approach technology development more incrementally, like Wernher von Braun's incremental approach with the Saturn V launch vehicle, but the political desire to demonstrate technological and political superiority over the Soviet Union derailed any technically sensible intermediate infrastructure forms. The political pressures to be successful with Apollo contributed to the consequence of failed long-term planning for human space exploration at NASA after Apollo.

The case of post-Apollo planning demonstrates a negative impact of Apollo– how not to develop and sustain a long-term strategic program of human space exploration. This was highlighted above with the fact that due to political pressures to achieve the Apollo goal, the technical system was not designed with stable, intermediate forms to allow use of the Apollo system in ways that were practical politically and economically for other functionality, like developing an infrastructure in LEO. Even though NASA leaders understood this problem, the political priority of Apollo thwarted the implementation of any solutions. To illustrate, during the Apollo era, von Braun mapped out a broad and strategic post-Apollo plan with multiple intermediate and stable forms. This is illustrated below in Figure 3.

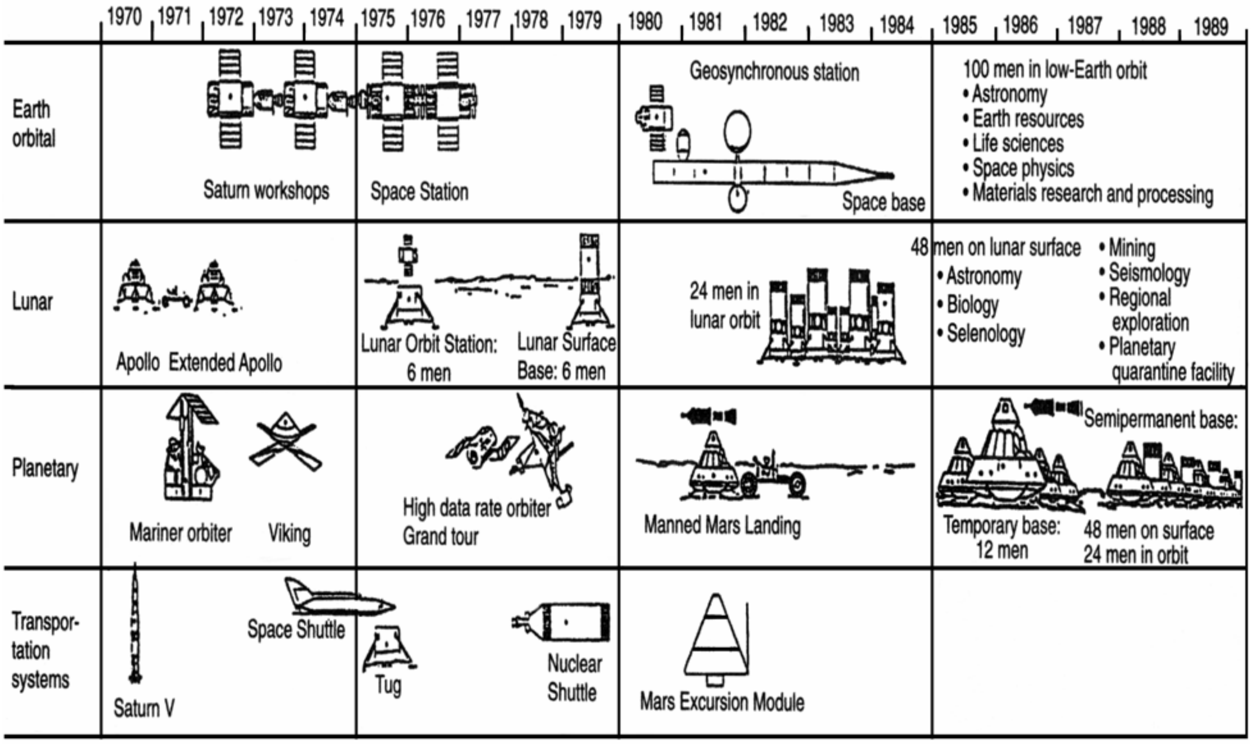

Figure 3. Post-Apollo Plans. Source: NASA History Office.

To add, Webb argued with President Kennedy in 1962 for a more balanced space program; Webb urged the President to view Apollo as one of NASA's priorities in addition to robotic scientific missions and application satellites.[100]

> "Kennedy… asked Webb a direct question about Apollo. 'Do you think that this is the top-priority program of the Agency?'
>
> Webb's answer stunned everyone… 'No, sir, I do not. I think it [Apollo] is one of the top-priority programs.' He started talking about the benefits of science, and some of the other things, apart from landing on the Moon, that rocket technology might achieve.
>
> 'Jim, I think it is the top-priority. I think we ought to have that very clear. Some of these other programs can slip… and nothing strategic is going to happen. But this [Apollo] is important for political reasons… This is, whether we like it or not, in a sense a race.'
>
> 'Look, I [Kennedy] know that all these other things and the satellites and the communications and the weather and all– they are all desirable, but they can wait.'
>
> 'Everything that we do ought to really be tied into getting onto the Moon ahead of the Russians.'
>
> '…[Apollo] is the top priority of the agency, and one of two things [including national defense]… the top-priority of the United States government… we ought to be clear, otherwise we should not be spending this kind of money [as much as 2% of all federal government outlays at the time of this discussion in 1962], because I am not that interested in space.'
>
> According to Seamans, there was no animosity between the President and NASA's Chief that day.
>
> I [Seamans] do not believe that he [Kennedy] made any moves afterwards to contradict Webb's thinking.
>
> …Webb could run NASA more or less as he saw fit.[101]

The moral of the story is that Webb could run NASA as he saw fit, given his personal relationship and influence with Kennedy, and President Johnson's more "hands-off" approach. But to accomplish Apollo, Webb postponed post-Apollo plans and programs, and approved the most expedient way to get to the Moon that undermined the use of Apollo as an infrastructure for future human spaceflight, and other, programs.

Transfer of Systems Management to the European Space Program

The U.S. helped European managers organize their programs and projects in ways that allowed success with civil European space efforts.[102] In the near-term to Apollo, this facilitated European success with large-scale space projects, the European Spacelab (ESL) and the Ariane launch vehicle. This was a result of the space cooperation between the two space programs. In the long-term, the transfer of systems management know-how resulted in European autonomy in space. U.S.-European intergovernmental space relations historically reflected power asymmetries in the U.S. favor. This pattern of cooperation eroded over time, as the European Space Agency (ESA) became more capable, particularly in the management area, due in large part to the cooperation with NASA. As a result, U.S.-European space relations concerning ISS, for instance, exhibit more equitable forms of cooperation in technological hardware contributions and decision-making dynamics.

The U.S. initially promoted international space cooperation with Europe as part of a strategy to recover the loss of prestige linked to the 1957 Sputnik 1 crisis.[103] This strategy involved the demonstration of political leadership among its European allies by engaging them in cooperative space ventures. Space leadership implied that institutional and resource asymmetries in NASA’s favor allow it to insist upon its preferences for space cooperation– “clearly defined and distinct managerial interfaces,” “no exchange of funds,” “distinct technical responsibilities,” and “protection of sensitive technology–” as preconditions for U.S.-European cooperation.[104] Europe was willing to accept these preferences, very often as a dependent and junior partner, to realize its specific functional preferences aimed at fostering space sciences programs, acquiring large-scale systems management and administrative know-how, and developing applied space technology capabilities.[105]

The initial years of cooperation took the form of bilateral arrangements involving launch services provided by the U.S. in exchange for some form of payload sharing on European scientific satellites. Agreements were reached between NASA and the United Kingdom, Italian, French, and German national space programs. With the institutionalization of a unified European effort in space sciences in 1964, represented by the European Space Research Organization (ESRO)[106] a series of MOUs were reached between NASA and ESRO. These MOUs facilitated NASA's launch services for a series of ESRO satellites in exchange for scientific results obtained from these missions. These satellite missions involved ESRO and High Eccentric Orbiting Satellite scientific satellite programs. In both of these programs, the Europeans extensively borrowed from NASA's systems management models used with Apollo.[107]

In addition to this, a policy of technology transfer, which was endorsed by U.S. President Johnson in 1966, was directed at the development of a European based expendable launch vehicle named Europa.[108] The European Community began these efforts in 1962 with the creation of the European Launch and Development Organization (ELDO). The willingness of the U.S. to allow for some technology transfer, such as in-flight hardware and technical information, was driven by foreign policy preferences. These preferences were to narrow the "technology gap" between the U.S. and Europe– a gap that was primarily in the managerial and organizational areas related to large-scale systems management capabilities.[109] Narrowing the gap was important to the U.S. in order to stimulate economic and industrial growth in Europe, and to enhance strategic alliances vis-à-vis the Soviet Union. Despite the efforts, ELDO failed in its attempts to develop Europa. The Europa program failed due to the inability of ELDO to acquire and adapt to the model of large-scale systems and engineering management. From its inception in 1962, ELDO was organized for failure.[110]

After U.S. Presidential and Congressional approval of NASA's Space Shuttle program in 1972, Europe pursued cooperation with NASA on ESL. Europe sought cooperation on ESL because of a lack of confidence in their own capabilities, especially in large-scale systems management know-how, and the belief that their technological and managerial capabilities could only be improved through cooperation with NASA.[111] Cooperation on ESL proved the European view correct, and ESL engendered an "Americanization," in terms of large-scale systems management and organizational techniques, of the European space effort. This played an important role in the technical success of ESL, the successful development of the Ariane launch vehicle, and Europe's enhanced space capabilities across-the-board from development of space science, telecommunications, and Earth observing satellite programs in the 1970s and 1980s.

The transfer of system management know-how used with Apollo to European space efforts translated into an equal cooperative partnership with the U.S. civil space program. Such a partnership indicates symmetry in European technological capabilities, interdependent cooperation outcomes in terms of contributions to critical path technologies and infrastructural components, participation in systems and technical management, and project leadership roles.[112] By the late 1980s, Europe's capabilities in expendable launch vehicle technology, and space science, telecommunications, and remote sensing satellites were not only comparable to that of NASA and the U.S., but from a commercial standpoint were competitive, and, at times, more successful in capturing market share. In its relations with Europe, the U.S. is faced with both cooperation and economic competition. The impact outlined here shifted the balance of power between the U.S. and European space programs. The transfer of systems management triggered a diminished European dependence on the U.S. space program, allowed for Europe to emerge as an genuine, more equal partner with the U.S. in civil space as exemplified by ESA's involvement with ISS, and enabled Europe to achieve autonomous space capabilities.

ECONOMICS

Examined in this section are the impacts and consequences of Apollo and the civil space program on the U.S. economy. The key question often asked and assessed is whether the civil space program is beneficial for the national economy. How NASA affects the U.S. economy consumes a large part of any debate about the Agency's programs and projects.[113] The problems involved in assessing the direct (first-order) benefits that NASA provides resulted in political advocates of continued increases in spending for the Agency to claim that the indirect (second-order) impacts of NASA's program on the economy are sufficient to justify its cost. In fact, the commissioning of studies to assess the economic benefits of the U.S. civil space program are undertaken with intentions to broaden support for NASA's budgetary allocations, and as evidence for congressional legislation dealing with the appropriation of NASA's budget.[114]

The common theme is that NASA expenditures, and space activities more generally, affect the economy as a source of job creation and employment, productivity gains, and through the development of new technologies that are spinoffs from space technologies creating an economic multiplier effect manifested in a return-on-investment (ROI).[115] Although there is evidence to support these economic impacts to a degree, it is noteworthy that the affects on the U.S. economy as a whole are not as large as claimed by NASA or by political advocates of the space program. NASA spent approximately $40 billion on R&D from 1961 to 1974. This represented 12% of total federal R&D spending in the U.S.[116] Even though civil space R&D is a large function of NASA, and federal government spending on R&D in space is a sizeable share of the overall federal R&D spending, the actual ROI of this R&D spending was observed to be at

14%, which correlated with other types of R&D spending.[117] Spending on NASA did bring with it a favorable ROI, but it did not produce the dramatic first-order economic benefits that could not be achieved by other types of government R&D spending.

By the 1980s, these impacts lessened. Space related R&D funding, which reached a peak of more than 20% of all U.S. R&D and more than 30% of all federal R&D in 1965, declined to a low of 3% of all U.S. R&D in the mid-1980s;[118] and it was determined that the relationships between aggregate U.S. technology changes and developments related to R&D spending on NASA are largely speculative.[119] Economists are unable to show a strong positive correlation between R&D spending and overall economic growth.[120] There are two primary reasons for this finding. The first one is that space related economic data involving data quality and collection is inadequate for economic impact analysis.[121] The second is that most government supported R&D is directed to the production of public goods, whose primary social value is not measured in real economic terms.

Public Goods

A host of activities take place in space to serve for the general benefit of society, including the use of space for national defense, environmental monitoring, and the collection of science data and information. According to the legislation that established NASA in 1958, the U.S. space program is to expand knowledge about Earth’s atmosphere and about outer space, develop and operate space vehicles, preserve the leadership of the U.S. in inventing and applying aeronautics and space technology, and cooperate with other nations in space projects. A special characteristic of these activities is that many people can benefit from them simultaneously without reducing their availability to others or adding to the costs of these activities. For instance, the benefits of

R&D are available to everyone, and increasing the number of citizens who benefits does not increase the costs of the activities. Activities with this type of attribute are known as public goods.

A gap in space economics research exists in the measure of intangible impacts associated with space exploration, such as education, national prestige and geopolitical influence, cultural influences, and a greater understanding concerning space science.[122] To ignore these intangible values leads to underestimating the public good benefits of space activities. This study here addresses in part some of these intangible aspects through an assessment of Apollo program impacts dealing with education, foreign policy, and cultural influences. In addition to this, a series of studies addressed the economic return emanating from NASA's space science programs.[123] Even though this specific impact is beyond the scope of this study, it is indicative of impacts as they relate to public goods.

Employment

Space activities are often judged as being good for the economy on the basis of direct job-creating potential, such as the number of jobs in the aerospace sector. Space-related jobs are also a cost, not a benefit, to the taxpayers who are not employed in the federal space program. As economists agree, wages belong on the cost side, not the benefit side, of the accounting ledger; for this reason, jobs are not properly the basis of measuring benefits of space activities.[124] The cost of carrying out any activity– the labor, facilities, and operations– is an expense whether carried out by the government or a private sector company.

Even if one wanted to make the case for space as a source of aerospace jobs, given that the bulk of space-related jobs are in aerospace, the macroeconomic impact on the U.S. is relatively small. Aerospace jobs account for less than 0.5% of total employment in the U.S. economy. Even at the peak of spending on Apollo in fiscal year 1966, the civil space program employed 400,000 while the total U.S. civilian employment stood at 74 million.[125] A further argument against the job creation impact is that many of the new technologies developed through space R&D can be considered labor-saving, productivity-type gains. This allows producers of goods and services to employ fewer people and maintain or even increase production levels. Important examples are robotic techniques and automated instrumentation.

Multiplier

Another prevalent view of economic impacts is that space activities lead to multiplier effects on the economy. The multiplier describes a relationship among activities in which one set of economic activities causes a host of other activities to take place, thus cascading the effects throughout the economy. In other words, it refers to the increased value of an investment or expenditure as it is used or flows through an economic system.[126] The multiplier theme relates to NASA's contributions to macroeconomic growth in productivity as a result of R&D investments.[127]

Macroeconomic studies that assessed productivity impacts, which can be attributed in large part to R&D expenditures with NASA's Apollo program, concluded that there is anywhere from 7 to 1, to a 14 to 1 cost ratio benefit.[128] Longer-term assessments placed the benefit at 9 to 1 over a twenty-year period (1974-1994).[129] These studies tended to indicate significant impacts on economic productivity as a result of civil space R&D. Concomitantly, these studies did contain some major liabilities as to the assumptions made, and subsequent studies refuted the favorable cost ratio benefits. For example, in a replication of one study that showed the 14 to 1 return, it was discovered that productivity changes from NASA R&D spending provided not to be statistically different from zero.[130] In 1990, A NASA study concluded that "because of the small size of NASA spending for R&D, and because of difficulties inherent in quantifying either the costs or benefits of R&D, single number claims… of the economic payoff of NASA R&D can be easily assailed."[131]

This conclusion reached by NASA is due to two factors. One is the fact that econometric modeling that underlies macroeconomic studies deal with an excessive number of variables in the economic equations used, and the economic projections as to multiplier effects are conditional on these variables that do change and are "fine-tuned" over time. The problems with the multiplier approach are so acute that the United States Office of Management and Budget (OMB), confronted with frequent use of the multiplier by many federal government agencies, issued guidelines for evaluating the benefits and costs of federal programs. OMB stated with regard to multiplier effects: "employment or output multipliers that purport to measure the secondary effects of government expenditures on employment and output should not be included in measured social benefits or costs." [132]

The second factor concerns how the inspirational value of Apollo, highlighted with the Apollo paradigm earlier in this study, impacted the economy. Even though it can argued that from a strict macroeconomic view NASA spending affects the economy no differently than other types of federal spending for goods and services,[133] Apollo fostered a wealth building process. The Apollo program is viewed as a "model" space program for assessing the impacts concerning wealth building processes that benefit the national economy in the U.S., as well as the global economy. Wealth building in this context refers to the combined use of engineering, technology, and human skills to maximize the creation, production, and delivery of goods and services that is needed to raise the standard of living, increase employment, spur education, and grow the national economy.[134] Aspects of all these wealth building processes are evident to an extent in the impacts of Apollo in the areas of public goods, employment, multiplier impacts discussed above, and in the technical spinoffs and educational impacts discussed below.

The Apollo program did lead to the further development and innovation in some industries, such as in helping to develop telecommunications systems for commercial use, more opportunities for space business in piloted spaceflight, and in information technologies.[135] The links between NASA, Apollo, and advances in satellite communications systems are examined in the spinoffs section below. The Apollo program positioned NASA as "new" source of government contracts. NASA informally used the "10% rule" for contracting; NASA kept 10% of funds in-house to train its own engineers and gain experience, and the remaining 90% went to industry.[136] This allowed some aircraft companies that were not involved with the space and missile business that began in the 1950s to enter the field, such as Grumman, which won a contract for the Apollo Lunar Module. Table 1 below highlights some of the major space projects linked to Apollo, which underlined the development of the space industry in the 1960s.

Table 1. Major Space Projects of the 1960s.[137]

Project Name	**Contractor**
Mercury Capsule	McDonnell
Gemini Capsule	McDonnell
Saturn IB; Saturn IC; Saturn S-II; Saturn S-IV	Chrysler; Boeing; North American; Douglas
Apollo Command and Service Module	North American
Apollo Lunar Excursion Module	Grumman
Surveyor	Hughes
Lunar Orbiter	Boeing

For example, in the area of informational technologies, North American, the contractor for the Apollo program spacecrafts (Command and Service Module), established a partnership with International Business Machines for an automated system to manage large bills of material for the construction of the spacecrafts. This led to the design and development of the Information Control System and Data Language/Interface. In 1969, this development became Information Management System/360 and applied in the Information Technology sector.

Spinoffs

NASA continually makes the case that concrete gains in social or economic value are a result of particular NASA-stimulated products or processes. The claim is that the return benefits of these products and processes– spinoffs– represent a significant dividend to the taxpayer and investment in aerospace-related R&D.[138] This concerns direct and indirect benefits from inventions and innovations resulting from NASA R&D programs, and patents and licenses resulting from R&D programs as a measure of the transfer of technology to the private sector.[139]

In the early 1960s, NASA established a technology utilization program with the objective to develop a means of transferring aerospace technology into useful applications by non-aerospace industries. In terms of Apollo-derived inventions, however, the economic impact is minimal. One study showed that none of the identified NASA-derived inventions are "major."[140] Another study that assessed the 1959 to 1979 time period, documented that of the 197 NASA patents licensed to industry 54 were commercialized.[141] This does represent some specific impacts, yet in the same time period NASA owned more than 3500 patents.[142]

NASA's technology utilization program was not successful in terms of direct tangible benefits since space systems and technologies are optimized for very specialized and complex functions that are unlikely to be adaptable to other needs.[143] A 1972 report regarding Apollo R&D spending, found that more than 50% of the technology spinoffs were employed within aerospace and defense sectors, and that the spinoffs only had a moderate economic impact, and relatively low scientific and social impacts.[144] Notwithstanding all this, there is value in information dissemination and publications describing advances in technology that could "in theory" be applied to help solve specific social problems. Most of the NASA documentation on spinoffs with commercial potential, do indeed focus on such an approach that is characterized by cutting-edge research that is underway or recently completed at NASA with plausible commercial realization following years later.

A key impact of spinoffs lie in secondary benefits through adaptation of advances in space technology to commercial development and use. During the Apollo era, NASA R&D played a role in the technology innovation process that established the infrastructure in the development of new industries, such as those based on communications satellites. Firms used NASA contracts to put them into a position to manufacture commercial space systems. This is exemplified by industrial R&D investments graphed in Figure 4 below; industrial R&D peaked in 1965-1966, and this paralleled the growth in federal funding for Apollo in the 1960s.

Nevertheless, the Cold War politics of the Apollo era impacted efforts in industry to capitalize on the technical infrastructure to commercialize space.[145] This is due to a number of factors that encompass: how national security concerns and superpower confrontation of the Cold War hindered the ability to form alliances with foreign companies and sell abroad; how private sector R&D was skewed toward satisfying NASA's technical agenda, which is not particularly congruent with commercial needs; how NASA was given responsibility for commercial policy in the space sector even though its culture was inimical to commercialization;

and how companies, through favorable cost-plus contracting and government subsidies, became dependent on the government and tended to follow whatever direction government funding marked out.

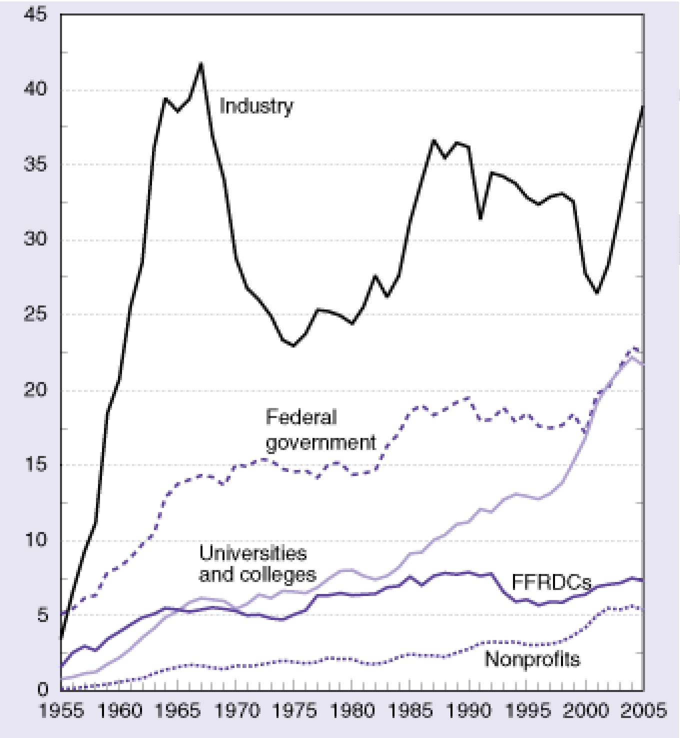

Figure 4. Research and Development Investments by Sector in Constant 2000 Dollars (billions). Source: National Science Foundation, *Science and Engineering Indicators* (Washington, DC: U.S. Government Printing Office, 2006).

This overall dependency on government was not necessarily negative for commercial prospects. As discussed above, the Apollo era facilitated the development of the technical know-how and infrastructure that was necessary for commercialization. In addition to this, national interests did exist to promote space commerce. The notable case here is that of space-based telecommunications systems. During the Apollo era, the U.S. pursued a foreign policy strategy of "space diplomacy" based on preeminence and leadership in all space sectors as well as "space for the benefit of all mankind."[146]

This strategy viewed the development of international telecommunications systems favorably. Two important developments followed. First, the U.S. Congress passed legislation that created a federal owned corporation, Comsat, with the goal to set up an international communications satellite system as soon as possible. This system was established through the creation of the International Telecommunications Satellite Consortium (Intelsat) of which Comsat was the leading entity as it managed and possessed a majority interest in Intelsat during the Apollo era. U.S. space policy goals “evinced the same spirit that informed Apollo: do something great in space, do it before the Soviets, and aim it in part at the Third World.”[147] These goals focused on national prestige and strengthening relations with developing states, while realizing regional and global telecommunications systems with the resulting economic impacts to society.

NASA made contractual investments in developing early (1960-1965) telecommunications systems. The first system, a passive communications satellite named Echo, was a NASA funded project;[148] the second system, an active system known as Telstar, was funded by AT&T in cooperation with NASA for space launch.[149] In addition, investments included: NASA’s Relay contract to RCA and Syncom contract to Hughes Aircraft; Comsat selection of Hughes’ geosynchronous orbiting satellites for its experimental test, and for its initial constellation of four satellites supported by a contract from NASA for the Apollo program; and a NASA contract to TRW in December 1965 for an advanced system of six spacecraft.[150] The U.S. government, in part due to impacts from the Apollo program, influenced advances in telecommunications satellite technology, and thus, the development of the satellite communications market.[151]

Over the course of Apollo, there were also a number of documented cases of technology utilization in the areas of electrical machinery, communications equipment, and instruments. A general surge of technological innovation is traceable to technology transfer from Apollo, not as inventions derived from the Apollo program, but as improvements and wider application of devices or materials already in existence, including improvements in production processes.[152] The impact was in causing technology advances to occur at an earlier time than would have likely taken place without NASA funding and support.

Within the context of this theme, there are several notable examples in relation to spinoffs, which include: requirements for computing capability and need for electrical component miniaturization in the Apollo spacecraft design; launch and guidance developments related to Apollo that triggered R&D in microelectronics, computer design, and software; application of digital imaging processing techniques, originally developed for analysis of the Moon photographs, to the enhancement of CATscan and magnetic resolution imaging medical data; the requirements with Apollo to monitor astronaut body functions stimulated progress in medical telemetry; and the demand for metallized films for temperature control on Apollo hardware and spacecraft that led to the development and application of such films to food packages, tents, space blankets for accident victims, and flame suites.[153]

One particular area of impact, often claimed by those in the space community[154] and verified in this study, deals with the spinoffs from the development of the Apollo Guidance Computer (AGC) concerning functionality and use of Integrated Circuits (ICs). In many ways, ICs helped create the computer industry by providing users with more speed and functionality. The relationship between computer users and computer manufacturers is symbiotic as the needs and demands of customers also spur the acceleration of new IC designs. Engineers often turn to

IC designers to help them achieve the goals of their own programs. An example of this is the Apollo space program, and the development therein, of the AGC. The decision, in 1962, to design the AGC using IC logic devices was critical to Apollo's computer success, and a key moment in the history of computing.[155]

The first computer to use ICs was the Block I version of AGC.[156] In designing AGC, engineers saw the IC as a way to reduce size and weight. In 1962, engineers decided to substitute ICs for individual transistors. To suit the needs of the Apollo mission, the Massachusetts Institute of Technology, which was contracted with designing AGC, specified its own IC "logic gate" chips, and developed a flight computer that incorporated thousands of these chips.[157] The use of ICs for the AGC impacted the IC industry at an important stage in its development, due to innovations in IC use for AGC, and due to demand for IC use for AGC that drove down the price of the circuits.[158] By 1963, this demand drove the IC price down by forty-fold.[159] This helped other industries find applications for ICs, and use of the technology proliferated more rapidly.

Technical applications, as a result of spinoffs, are also evident in the longer-term relative to Apollo. Since 1976, NASA publishes a report, *Spinoffs*, highlighting technical applications as a result of NASA investments. In addition to this, presidential and congressional policies encouraged NASA to move beyond undertaking fundamentally space-based activities to a broader role in providing new technologies for commercial markets on Earth.[160]

Despite these examples, economists urge caution about the use of spinoffs as an appropriate measure of the benefits of space activities. Spinoffs as a measure of technical innovation involve upstream development dealing with R&D investments, and then downstream processes of turning these investments into economic value. As this section discussed, the upstream links to Apollo exist, but the downstream processes are limited. While spinoffs do occur from upstream development, and this is evidence of a potential economic impact, there is an issue when the spinoffs become the basis for justifying space expenditures given the limited downstream links that can be documented. The argument offered by critics is that if consumers wanted, or this is market demand, for these new products, then funding R&D specifically directed toward those products is more effective. While spinoffs bring social benefits, their costs of development undertaken indirectly as a part of a space project is more expensive than their costs of developing them directly due to that fact that these impacts are at best indirect in relation to the mission objectives of any space program.[161]

Other Economic Impacts

There are examples where Apollo fostered other economic impacts not discussed earlier. These impacts are in two areas. One, is the local economic impact as a result of tourists going to visit NASA centers and view space launches, such as the impact on restaurants and hotels near the Kennedy Space Center benefiting from expenditures by visitors going to the Center to view launches. Apollo 11, for example, led to local economic impacts on the county in Florida where Kennedy Space Center is located.[162] These impacts concerned increased spending and tax monies to the county. In this case, costs to the county were minimal in comparison to the economic benefits, and the intangible benefits received from the Apollo 11 launch were believed to be immeasurable, like visibility for the county.[163]

The problem with this impact is that it counts as benefits what are in fact transfers of income from some consumers and producers to other consumers and producers.[164] It also overlooks other, less desirable transfers of economic burdens like traffic congestion and higher prices for residents near the NASA Centers. In addition, if the impacts are added to the primary activity, then the multiplier can be large for any activity that involves the public. Hence, the impacts related to Apollo in this example are not unique as there is no discriminating among the economic value of different activities.

The second area of impact deals with economic development as a result of location of field centers, and the contractual partnerships with industry to enable the large-scale technological development needed for Apollo. These partnerships provided jobs and skills to diverse areas of the U.S., in particular the Southern states with relatively low-income and less industrialization and urbanization than many other parts of the U.S. Despite this development, high-income, industrialized and urbanized states received the larger share of NASA R&D allocations during Apollo and afterwards.[165]

Further, the links between spinoffs and multiplier impacts, and regional economic development are weak. Research undertaken on the economic impacts of allocation of federal R&D among states found that neither scientific nor technical innovation can be expected to bring benefits to the geographic region in which they are located, and there is little indication that federal R&D expenditures are effective in generating regional economic growth.[166] There are links between benefits to a region on the basis of technical workforce that space activities generate and require, as this workforce is a versatile resource that is productive and transferable to non-space sectors. If many of the aerospace jobs are concentrated in a geographical region, then these jobs can become a benefit to people living in the region.[167] This is a benefit that members of congress carefully preserve.

EDUCATION

The quality of STEM education in the U.S. is an ongoing concern of scientists, engineers, and decision-makers. Following World War II, scientists, engineers, and mathematicians expressed concerns about the quality of pre-college instruction in their fields, and on the number of students who go on to college and study STEM subjects. The curriculum was out-of-date and difficult for teachers to master in order to develop an understanding of the key concepts and ideas in STEM fields.[168] The crisis in education was further created by the beginnings of the space age with the launch of Sputnik 1 in 1957.

One of the primary forces shaping the science reforms of the 1950s and 1960s was the National Science Foundation (NSF). Founded in 1950, the NSF's education effort, prior to Sputnik 1, was confined to promoting science fairs and clubs and funding summer institutes for teachers. Following Sputnik 1, in 1958, the NSF increased its support for curriculum development at a rapid pace. By 1960, the programs of the Education Directorate at NSF represented 42% of the NSF annual budget.[169] This science reform movement was sustained through the Apollo program, and subsequently, ended with the Apollo 11 lunar landing in 1969.[170]

NASA, through the application of its programs and projects, played a role in inspiring youth and fostering impacts on STEM education. As a whole, NASA investment in STEM areas beginning with the Apollo era, and sustained to the present, encompass: curriculum and teaching enhancement activities for K-12; supplemental training in STEM subjects for college teachers; cooperative education and work-study programs; and university and college grants and assistantships. These are the principal means by which NASA sought to promote the continuing replenishment of the U.S. STEM workforce.

During Apollo, there was a dramatic increase in the number of American (U.S. Citizen) students pursuing advanced degrees in STEM disciplines. As the Apollo program was terminated and NASA's funding cut, the number of students going into STEM fields correlates with the downward trend in NASA's budget. This is illustrated in Figure 5 as it relates to the number of U.S. citizen doctorates (Ph.D.s) in technical fields.

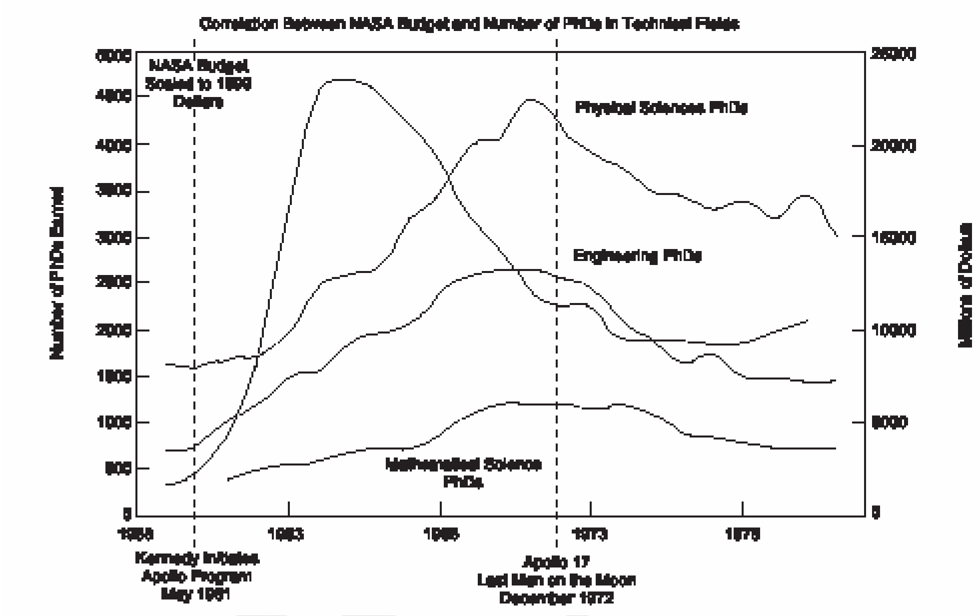

Figure 5. Educational Impacts of the Apollo Program. Source: Office of Management and Budget, "Space Activities of the U.S. Government," 2002.

Given NASA's share of the entire federal R&D budget, particularly in the Apollo era, its investment in higher education in STEM fields is relatively large as comparable to other educational investments in the U.S. federal government. In 1965, for instance, NASA allocations to its university related programs and research amounted to more than 85% of all 1965 non-NASA federal appropriations to universities.[171] Following the successful Apollo 11 mission to the Moon, R&D obligations in the industrial sector declined and did not experience another surge until over a decade later, when Cold War investments in military technology resulted in another period of growth. This decline, graphed in Figure 4, resulted in a negative impact on STEM education as Figure 5 illustrates.

The downward trends showed in Figure 5 highlights the present situation where the U.S. need for the highest quality human capital in STEM areas is not being met, and by some accounts there is a major workforce crisis in the aerospace, defense industrial sector.[172] In physics and advanced mathematics, U.S. high-school seniors score significantly below the international average on performance tests.[173] The trend continues at the undergraduate university and college level. This decline is also reflected in the downward trend of the U.S. relative to other states in science and engineering university degrees granted per capita.[174] At the graduate level, the problem continues; at U.S. universities, 25% of graduate students in the sciences, and nearly 40% of the graduate students in STEM disciplines, are foreign nationals.[175]

A contributing factor to all these tends is a general disinterest in STEM fields. The argument that money put into the space program is better spent by putting it directly into the educational system to encourage students to pursue STEM areas is a misconception as the U.S. is already one of the top spenders per student in the world.[176] The bottom line is that students need something to inspire their efforts, an "imagination capital," and thus, the impact of space exploration as positively impacting STEM education is without precedent as is evident with aspects of the Apollo Paradigm and inspirational value of Apollo as explained in this study.

University Programs

During the Apollo era, NASA established a Sustaining University Program (SUP) that envisioned the university as a repository of knowledge to meet public goals and general societal problem-solving.[177] NASA established SUP in 1962. SUP was Webb's primary vehicle for relating NASA to societal purposes.[178] This program, though, highlighted the problematic nature of relations between government and universities. The university feels its essential character to be threatened when the government attempts too firmly to direct it along any given path. In addition, science at the university and college levels was more oriented to goals defined by society, like social, urban, and environmental problems.

Even though SUP's goal was to further university and college interest in the integration and synthesis of knowledge, the impacts of the program were limited to the aeronautics and space goals as established by NASA.[179] SUP was not able institutionalize the educational innovations that it sought. There is no direct evidence that the long-range goals of NASA's SUP program were met.[180] These goals involved the development of a university capable to respond as an institution to societal problems and issues, capability for multidisciplinary and interdisciplinary research and teaching, concern with space as a societal problem, and acceleration of knowledge transfer from the university or college to society.

CONCLUSIONS

The rationale for this study began with the notion that the historical claims regarding societal benefits that are linked to the Apollo program are societal and human, rather then technical. The findings indicate that both exist. The results of the study further suggest that the direct, or first-order, societal impacts of Apollo are limited and confined more so to the Apollo era. Such impacts were found to exist in a number of areas from city planning, systems architecture, economics, and education. One common theme regarding all these areas is that impacts clearly exist "in theory," but are generally limited in practice to a few specific cases, like PERT, Information Management System/360, ICs, and the economic and educational benefits that are linked to federal investments in space-related R&D. Even in the economic and education areas, which are most often associated with positive impacts on society, the claims are greater than the actual economic evidence suggests, and the first-order benefits in many cases are no different than that which can result from other types of federal investments involving R&D.

The indirect, or second-order, societal impacts traced to Apollo are much broader and are sustained to the present. Of significance, is how the political formulation of Apollo put into place a paradigm that served as the conceptual basis for Apollo program impacts. This paradigm was based on a technological ethos based on the idea that the technology and know-how acquired with Apollo could be applied to the space program and elsewhere, to establish what was then called Space Age America and Space Age Management. The European space program benefited from the transfer of managerial know-how used with Apollo. Also, it is this notion of Space Age Management that led NASA to emulate the technical and management models of Apollo to implement the current U.S. Vision for Space Exploration.

The value of Apollo lies primarily with second-order impacts and consequences. An important gauge of this is how the inspirational value of Apollo did more for building wealth than probably any other civil, peaceful pursuit. This “wealth factor” was evident in a variety of ways and encompasses most significantly: the role of Apollo in engendering prestige, confidence, and competence for the U.S. government; Apollo as a “grand laboratory” for the developments, innovations, and applications of technologies for societal benefit; the role that Apollo played in the development of the space industry; and the motivation that Apollo provided for students to pursue STEM disciplines.

From a broader historical perspective, one cannot predict what space exploration will bring. Undoubtedly, it will bring with it, as Apollo did, changes in how humanity views planet

Earth, and on how humans and institutions interact with society. Space exploration informs us of the grandiose search for, and interaction with our future, our destiny. The space odyssey is perpetuated through time by explorers, discoverers, and seekers. Explorers venture into the unknown cosmos; discoverers pursue cumulative knowledge about the Earth and space; and seekers search for underlying models and causal factors to explain cosmological phenomena. Apollo was about our future– it set humanity on a trajectory to interact with the future, to in the end, become a spacefaring species and society.

NOTES

[1] This is a view shared by many advocates of space exploration, and is reflected in space history literature. See, among others, Roger D. Launius, "Historical Dimensions of the Space Age," in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002); Walter A McDougall, …*The Heavens and the Earth, A Political History of the Space Age* (Baltimore, Maryland: The Johns Hopkins University Press, reprinted in 1997); and Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space* (New York, New York: Random House, 1994).

[2] Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space* (New York, New York: Random House, 1994).

[3] Ibid.

[4] Walter A McDougall, …*The Heavens and the Earth, A Political History of the Space Age* (Baltimore, Maryland: The Johns Hopkins University Press, reprinted in 1997).

[5] See Roger D. Launius, "Overview: What is a Turning Point in History, and what were they for the Space Age?," Societal Impact of Spaceflight Conference, NASA History Division and National Air and Space Museum Department of Space History, September 19-21, 2006, Washington, DC. This paper explores plausible definitions of "turning points" in history. Although there is not a clear definition of a turning point, most historians, if not all, would agree that the "focusing events" that marked the rise of the Space Age, like Sputnik and Apollo, do indeed represent historical turning points.

[6] Roger D. Launius, *Apollo: A Retrospective Analysis*, Monographs in Aerospace History No. 3 (Washington, DC: NASA SP-2004-4503, reprinted in July 2004).

[7] Andrew Chaiken, "The Impact of Apollo," Societal Impact of Spaceflight Conference, NASA History Division and National Air and Space Museum Department of Space History, September 19-21, 2006, Washington, DC.

[8] Gerald M. Steinberg, "Large-scale National Projects as Political Symbols," *Comparative Politics* 19:3 (1987).

[9] Murray Edelman, *The Symbolic Uses of Politics* (Urbana, Illinois: University of Illinois Press, 1974).

[10] Van Dyke, *Pride and Power: The Rationale for the Space Program* (Urbana, Illinois: University of Illinois Press, 1964).

[11] Hans Morgenthau, *Politics Among Nations: The Struggle for Power and Peace* (New York, New York, Knopf, 1972).

[12] Van Dyke, *Pride and Power: The Rationale for the Space Program* (Urbana, Illinois: University of Illinois Press, 1964); and Amitai Etzioni, *Moon Doggle: Domestic and International Implications of the Space Race* (New York, New York: Doubleday, 1964).

[13] John M. Logsdon, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge, Massachusetts: MIT Press, 1970).

[14] Don K. Price, *The Scientific Estate* (Cambridge, Massachusetts: Harvard University Press, 1965).

[15] James L Kauffman, *Selling Outer Space: Kennedy, the Media, and Funding for Project Apollo, 1961-1963* (Tuscaloosa, Alabama: University of Alabama Press, 1994).

[16] Walter A McDougall, …*The Heavens and the Earth, A Political History of the Space Age* (Baltimore, Maryland: The Johns Hopkins University Press, reprinted in 1997).

[17] *Effects of the Moon Landing on Opinions in Six Countries*, United States Information Agency, Office of Research and Assessment, September 12, 1969.

[18] There are historians that have critiqued the associations made between Apollo, and westward expansion and manifest destiny. See Patricia N. Limerick, "Imagined Frontiers: Westward Expansion and the Future of the Space Program," in Byerly, Radford, ed., *Space Policy Alternatives* (Boulder, Colorado: Westview Press, 1992).

[19] James L Kauffman, *Selling Outer Space: Kennedy, the Media, and Funding for Project Apollo, 1961-1963* (Tuscaloosa, Alabama: University of Alabama Press, 1994).

[20] Roger D. Launius, "Overview: What is a Turning Point in History, and what were they for the Space Age?," Societal Impact of Spaceflight Conference, NASA History Division and National Air and Space Museum Department of Space History, September 19-21, 2006, Washington, DC.

[21] Cited from Walter A. McDougall, …*The Heavens and the Earth, A Political History of the Space Age* (Baltimore, Maryland: The Johns Hopkins University Press, reprinted in 1997): 320.

[22] Ibid.: 139.

[23] Walter A. McDougall, …*The Heavens and the Earth, A Political History of the Space Age* (Baltimore, Maryland: The Johns Hopkins University Press, reprinted in 1997).

[24] James E. Webb, *Space Age Management: The Large-Scale Approach* (New York, New York: McGraw-Hill Book Company, 1969).

[25] Roger D. Launius, *Apollo: A Retrospective Analysis*, Monographs in Aerospace History No. 3 (Washington, DC: NASA SP-2004-4503, reprinted in July 2004).

[26] Howard E. McCurdy and Roger D. Launius, "If We Can Go to the Moon…: Political Power and Public Confidence," [undated and unpublished manuscript].

[27] Statistical data is graphed in Howard E. McCurdy and Roger D. Launius, "If We Can Go to the Moon…: Political Power and Public Confidence," [undated and unpublished manuscript]; also, see Herbert E. Krugman, "Public Attitudes Toward the Apollo Space Program, 1965-1975," *Journal of Communication* (Autumn 1977).

[28] "Public Support for the United States Space Program: Results from a National Tracking Study of Registered Voters," prepared for Rockwell International, Yankelovich Partners Inc., June 1994; and "Public Support for the U.S. Space Program," Yankelovich Partners Inc., 1993.

[29] *Findings from a Research Project about Attitudes toward Government*, The Council for Excellence in Government, Washington, DC, March 21, 1997.

[30] "Public Support for the United States Space Program: Results From a National Tracking Study of Registered Voters," prepared for Rockwell International, Yankelovich Partners Inc., June 1994; and "Public Support for the U.S. Space Program," Yankelovich Partners Inc., 1993.

[31] Howard McCurdy, Space and the American Imagination (Washington, DC: Smithsonian Institute Press, 1997).

[32] Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space* (New York, New York: Random House, 1994): 285.

[33] Roger D. Launius, *Apollo: A Retrospective Analysis*, Monographs in Aerospace History No. 3 (Washington, DC: NASA SP-2004-4503, reprinted in July 2004).

[34] Cited form Andrew Chaiken, *Man on the Moon* (New York, New York: Viking, 1994).

[35] Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space* (New York, New York: Random House, 1994).

[36] Denis Cosgrove, "Contested Global Visions: One-World, Whole-Earth, and the Apollo Space Photographs," *Annals of the Association of American Geographers* 84: 2 (1994).

[37] Frank White, *The Overview Effect: Space Exploration and Human Evolution* (Reston, Virginia: American Institute of Aeronautics and Astronautics, second edition, 1998).

[38] Roger Launius, "Heroes in a Vacuum: The Apollo Astronaut as Cultural Icon," 43rd AIAA Aerospace Sciences Meeting, AIAA 2005-702, 10-13 January 2005, Reno, Nevada.

[39] Eligar Sadeh, "Human Mission from Earth: Finding Rationales for Exploration of the Moon and Mars," *Space Policy* 17:3 (2001).

[40] Ancillary policy is a policy of continuation and incrementalism. This is the norm for public policy making in the United States Congress. Ancillary does not solve an identified national problem and is more apt to represent a

continuing government commitment, even though the bureaucracy it maintains may have been set up for that purpose long ago. Ancillary policy has low agenda status; it receives only limited public attention, public funds, and efforts of public officials. See Roger D. Launius and Howard E. McCurdy, eds., *Spaceflight and the Myth of Presidential Leadership* (Chicago, Illinois: University of Illinois Press, 1997).

[41] Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore, Maryland: The Johns Hopkins University Press, 1993).

[42] *The Post-Apollo Space Program: Directions for the Future*, Space Task Group, September 1969.

[43] *Pioneering the Space Frontier*, Report of the National Commission on Space (New York, New York: Bantam Books, 1986); Sally K. Ride, *Leadership and America's Future in Space*, A Report to the NASA Administrator (Washington, DC: Government Printing Office, August 1987); *Report of the 90-Day Study on Human Exploration of the Moon and Mars*, NASA Report Prepared for the NASA Administrator (Washington, DC: NASA, November 1989); Norm R. Augustine, *Report of the Advisory Committee on the Future of the U.S. Space Program* (Washington, DC: Government Printing Office, 1990); and Thomas P. Stafford, *America at the Threshold: America's Space Exploration Initiative* (Washington, DC: Government Printing Office, 1991).

[44] Thomas P. Stafford, *America at the Threshold: America's Space Exploration Initiative* (Washington, DC: Government Printing Office, 1991).

[45] Sally K. Ride, *Leadership and America's Future in Space*, A Report to the NASA Administrator (Washington, DC: Government Printing Office, August 1987).

[46] NASA Administrator Daniel S. Goldin put into place a strategic planning process at NASA during his tenure as Administrator from 1992 to 2001 as mandated by the United States Congress (i.e., Congressional Government Performance and Results Act). The common planning process led to a realignment of NASA programs and projects to fit the goals and objectives of that plan. See Charles Pellerin, Former NASA Associate Administrator for Strategic Planning, NASA, Interview by author on November 27, 1995; and Alan M. Ladwig and Gary A. Steinberg, *Strategic Planning and Strategic Management within NASA*, 1996 [unpublished report].

[47] *The New Age of Exploration: NASA's Direction for 2005 and Beyond*, NASA; and *2006 NASA: Strategic Plan*, NASA.

[48] Eligar Sadeh, "Management Dynamics of NASA's Human Spaceflight Programs," *Space Policy* 22: 4 (2006).

[49] *Science*, November 15, 1968.

[50] Stephen B. Johnson, "From Concurrency to Phased Planning: An Episode in the History of Systems Management," in Thomas P. Hughes and Agatha C. Hughes, eds., *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After*, (Cambridge, Massachusetts: MIT Press, 2000).

[51] Stephen B. Johnson, "History of Space Business," in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[52] Stephen B. Johnson, *The United States Air Force and the Culture of Innovation, 1945-1965* (Washington, DC: United States Air Force, 2001).

[53] Stephen B. Johnson, *The Secret of Apollo: Systems Management in the American and European Space Programs* (Baltimore, Maryland: The Johns Hopkins University Press, 2002).

[54] "PERT did not build the Polaris, but it was extremely useful for those who did build the weapon system to have many people believe that it did… the program's innovativeness in management methods was… as effective technically as rain dancing... it mattered not that management innovations contributed little directly to the technical effort; it was enough that those outside the program were willing to believe that management innovation had a vital role in the technical achievements of the Polaris." See Harvey Sapolsky, *The Polaris Systems Development* (Cambridge: Harvard University Press, 1972): 125, 246.

[55] Stephen B. Johnson, *The Secret of Apollo: Systems Management in the American and European Space Programs* (Baltimore, Maryland: The Johns Hopkins University Press, 2002).

[56] George Mueller, interviewed by Martin Collins, National Air and Space Museum, May 2, 1988.

[57] Ibid.

[58] James E. Webb, *Space Age Management: The Large-Scale Approach* (New York, New York: McGraw-Hill Book Company, 1969); Arnold Levine, *Managing NASA in the Apollo Era* (NASA SP-4102, 1982); W. Henry Lambright, *Powering Apollo: James E. Webb of NASA* (Baltimore, Maryland: The Johns Hopkins University Press, 1995); Sylvia K. Kraemer, "Organizing for Exploration," in Logsdon, John. ed., *Exploring the Unknown, Selected Documents in the History of the U.S. Civil Space Program, Volume I: Organizing for Exploration* (Washington, DC: NASA History Office, 1995); and Robert C. Seamans, *Project Apollo: The Tough Decisions*, Monographs in Aerospace History No. 37 (Washington, DC: NASA SP-2005-4537, 2005).

[59] Roger D. Launius, *Apollo: A Retrospective Analysis*, Monographs in Aerospace History No. 3 (Washington, DC: NASA SP-2004-4503, reprinted in July 2004).

[60] *Apollo Program Management*, Staff Study for the Subcommittee on NASA Oversight, Committee on Science and Astronautics, United States House of Representatives, Ninety-First Congress (Washington, DC; Government Printing Office, 1969).

[61] Stephen B. Johnson, *The Secret of Apollo: Systems Management in the American and European Space Programs* (Baltimore, Maryland: The Johns Hopkins University Press, 2002).

[62] Robert C. Seamans, *Project Apollo: The Tough Decisions*, Monographs in Aerospace History No. 37 (Washington, DC: NASA SP-2005-4537, 2005).

[63] Erasmus H. Kloman, "NASA Organization and Management from 1961 to 1965: The Vision and the Reality," in Hoban, Francis T, ed., *Issues in NASA Program and Project Management* (Washington, DC: NASA SP-6101-02, 1989); and Phillip K. Tompkins, *Apollo, Challenger, Columbia: The Decline of the Space Program, A Study in Organizational Communication* (Los Angeles, California: Roxbury Publishing Company, 2005).

[64] James E. Webb, *Space Age Management: The Large-Scale Approach* (New York, New York: McGraw-Hill Book Company, 1969).

[65] Arnold Levine, *Managing NASA in the Apollo Era* (Washington, DC: NASA SP-4102, 1982).

[66] Dr. Hugh L. Dryden was Director of the National Advisory Committee for Aeronautics from 1947 until the creation of NASA. He was named Deputy Administrator of NASA in 1958, and served in that capacity until his death in 1965. Dr. Dryden gained a broad knowledge of aeronautics in his career, and in service on numerous technical groups and scientific advisory committees for the United States military and other agencies of the United States government.

[67] In 1960, Robert C. Seamans joined NASA as an Associate Administrator. In 1965, after the death of Dryden, he became Deputy Administrator. During his years at NASA, he worked closely with the United States Department of Defense in research and engineering programs. Seamans advised NASA on the developments in the military space program that were of relevance for public management at the Agency, such as systems management and systems engineering.

[68] http://www.bartlett.ucl.ac.uk/research/management/ICE_paper.pdf (accessed June 9, 2005)– Peter Morris, *Science, objective knowledge, and the theory of project management*, ICE James Forrest Lecture, University College of London.

[69] *Exploration Systems Architecture Study, Final Report* (Washington, DC: NASA TM-2005-21406, November 2005).

[70] NASA Administrator Michael Griffin described the new spacecraft intended to fulfill United States President Bush's national vision for a manned return to the moon as "Apollo on steroids." *The American Institute of Physics Bulletin of Science Policy News*. Number 138, September 22, 2005.

[71] Michael D. Griffin, Remarks at the Mars Society Convention, Washington, DC, August 3, 2006.

[72] Eligar Sadeh, "Public Management Dynamics of NASA: Interview with NASA Associate Administrator Rex Geveden," *Astropolitics* 4: 1 (2006).

[73] http://iemp.nasa.gov (accessed September 8, 2006).

[74] Eligar Sadeh, "Management Dynamics of NASA's Human Spaceflight Programs," *Space Policy* 22: 4 (2006).

[75] Eligar Sadeh, "Public Management Dynamics of NASA: Interview with NASA Associate Administrator Rex Geveden," *Astropolitics* 4: 1 (2006).

[76] The position of *the* Associate Administrator at NASA was established in 2005. This position is effectively the number two official at NASA. *The* Associate Administrator is responsible for all technical operations of the Agency, and works directly with the NASA Administrator to develop strategy and policy, including managerial oversight of NASA's programs and field centers. Rex Geveden, whom the author interviewed for this study, is currently (as of September 2006) in this position at NASA.

[77] Eligar Sadeh, "Public Management Dynamics of NASA: Interview with NASA Associate Administrator Rex Geveden," *Astropolitics* 4: 1 (2006).

[78] http://pbma.hq.nasa.gov/ita_main_cid_501 (accessed February 7, 2006). NASA's Independent Technical Authority is part of NASA's Process Based Mission Assurance Knowledge Management System,

[79] Geveden, Rex, NASA Chief Engineer, "Putting Technical Authority into Practice," paper presented at the NASA Project Management Challenge Conference 2005, March 21-23, 2005, University of Maryland.

[80] The Aerospace Safety Advisory Panel is a senior advisory committee that reports to NASA and the United States Congress. The Panel was established by congress after the Apollo 204 Command and Service Module spacecraft fire

in January 1967. The statutory authority of the Panel, as stated in the NASA Authorization Act of 1968 (United States Congressional Public Law 90-67), is to review NASA's safety standards and operations plans. In a recent review (August 18, 2005) of the Panel, the Independent Technical Authority was viewed as addressing the cultural issues of safety and providing checks and balances for NASA. The Panel concluded that strong measures are in place to keep the Technical Authority independent and separated from program and project managerial control.

[81] Eligar Sadeh, "Management Dynamics of NASA's Human Spaceflight Programs," *Space Policy* 22: 4 (2006).

[82] Eligar Sadeh, "Public Management Dynamics of NASA: Interview with NASA Associate Administrator Rex Geveden," *Astropolitics* 4: 1 (2006).

[83] *A Budgetary Analysis of NASA's New Vision for Space Exploration*. 2004. United States Congressional Budget Office.

[84] NASA initiated a full-cost concept in 1995, but began budgeting and accounting in full-cost in fiscal year 2004. See http://iemp.nasa.gov (accessed on February 7, 2006).

[85] While the total of NASA's budget will likely not change, full-cost will likely increase the costs of projects, at least in the near-term.

[86] Tim Owen, Full Cost Training Lead, NASA Headquarters and Marshall Space Flight Center Financial Offices, "A Project Manager's View of Full Cost," paper presented at the NASA Project Management Challenge Conference 2005, March 21-23, 2005, University of Maryland.

[87] Eligar Sadeh, "Management Dynamics of NASA's Human Spaceflight Programs," *Space Policy* 22: 4 (2006).

[88] Gary D. Brewer, "Perfect Places: NASA as an Idealized Institution," in Byerly, Radford, ed., *Space Policy Reconsidered* (Boulder, Colorado: Westview Press, 1989); Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore, Maryland: The Johns Hopkins University Press, 1993); and Phillip K. Tompkins, *Apollo, Challenger, Columbia: The Decline of the Space Program, A Study in Organizational Communication* (Los Angeles, California: Roxbury Publishing Company, 2005).

[89] Sylvia K. Kraemer, "Organizing for Exploration," in Logsdon, John, ed., *Exploring the Unknown, Selected Documents in the History of the U.S. Civil Space Program, Volume I: Organizing for Exploration* (Washington, DC: NASA History Office, 1995).

[90] The model of corporate power indicates that NASA's industrial contactors in the Aerospace-Defense sector assumed more control, and associated responsibilities, relative to NASA. During Apollo, contractor penetration was practiced by NASA, and NASA possessed the in-house technical capacity for close contractor oversight and monitoring, as well as more of a role in systems integration. As Apollo came to fruition in 1968-1969, the balance of power began to shift as the contactor assumed the lead role in systems integration, and NASA became more of an oversight bureaucracy with diminished capacity for monitoring and penetrating the contactor.

[91] Stephen B. Johnson, *The Secret of Apollo: Systems Management in the American and European Space Programs* (Baltimore, Maryland: The Johns Hopkins University Press, 2002).

[92] Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore, Maryland: The Johns Hopkins University Press, 1993).

[93] Frank B. Coker, "How to Streamline the Translation of Aerospace Techniques to Non-Aerospace Applications, paper presented at the AIAA Third Annual Meeting, Boston, Massachusetts, November 29–December 2, 1968; and Vernal M. Tyler and Carl F. Asiala, The Aerospace Role in Planning Cities of the Future, paper presented at the AIAA Third Annual Meeting, Boston, Massachusetts, November 29–December 2, 1968; and Thomas O. Paine, Space Age Management and City Administration, *Public Administration Review* 29 (1969).

[94] Vernal M. Tyler and Carl F. Asiala, The Aerospace Role in Planning Cities of the Future, paper presented at the AIAA Third Annual Meeting, Boston, Massachusetts, November 29–December 2, 1968.

[95] Thomas O. Paine, Space Age Management and City Administration, *Public Administration Review* 29 (1969).

[96] Frank B. Coker, "How to Streamline the Translation of Aerospace Techniques to Non-Aerospace Applications, paper presented at the AIAA Third Annual Meeting, Boston, Massachusetts, November 29–December 2, 1968; and Harold D. Watkins, "Systems Engineering Aids Social Problems," *Aviation Week and Space Technology*, January 31, 1966.

[97] Mark W. Maier and Eberhardt Rechtin, *The Art of Systems Architecting* (United Kingdom: Taylor and Francis, CRC Press, second edition, 2000).

[98] Ibid.

[99] For a detailed historical account of the decision at NASA to go with lunar orbital rendezvous, see James R. Hansen, *Enchanted Rendezvous: John C. Houbolt and the Genesis of the Lunar-Orbit Rendezvous Concept*, Monographs in Aerospace History, No. 4 (Washington, DC: NASA, 1999).

[100] There was a tape recording of a White House meeting that took place on November 21, 1962 during which President Kennedy made clear his administration's priority that the United States land on the moon before the Soviet Union. The tape is particularly noteworthy for the window it provides into presidential decision making. Faced with the option of directing federal funds more generally across the entire space program, President Kennedy argued with NASA Administrator James E. Webb for a more focused approach toward the lunar landing. Having such a goal, the President argued, would carry the country's entire space effort forward and have the same outcome NASA was seeking. See http://www.jfklibrary.org (accessed September 12, 2006)– *Presidential Meeting in the Cabinet Room of the White House, November 21, 1962. Presidential Recordings Collection tape #63.*

[101] Cited from Piers Bizony, *The Man Who Ran the Moon, James E. Webb, NASA, and the Secret History of Project Apollo* (New York, New York: Thunder's Mouth Press, 2006): 86-89. Note that the citation is based 'verbatim' on a transcript of the Presidential recording referred to in the previous note. Also, the comments quoted and attributed to Seamans are based on an interview that Bizony conducted with Seamans in September 2005.

[102] Stephen B. Johnson, *The Secret of Apollo: Systems Management in the American and European Space Programs* (Baltimore, Maryland: The Johns Hopkins University Press, 2002).

[103] Lorenza Sebesta, *United States-European Cooperation in Space During the Sixties*, ESA HSR-14 (Noordwijk, Netherlands: ESA Publications Division, July 1994).

[104] Eligar Sadeh, "International Space Cooperation," in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[105] Stephen B. Johnson, *The Secret of Apollo: Systems Management in the American and European Space Programs* (Baltimore, Maryland: The Johns Hopkins University Press, 2002).

[106] The European Space Agency was formed in 1975 on the basis of the European Space and Research Organization.

[107] Arturo Russo, *The Definition of Scientific Policy: ESRO's Satellite Programme in 1969-1973*, ESA HSR-6 (Noordwijk, Netherlands: ESA Publications Division, March 1993); Arturo Russo, *Choosing ESRO's First Scientific Satellites*, ESA HSR-3 (Noordwijk, Netherlands: ESA Publications Division, November 1992); and Arturo Russo, *ESRO's First Scientific Satellite Programme, 1961-1966*, ESA HSR-2 (Noordwijk, Netherlands: ESA Publications Division, October 1992).

[108] The restraints on technology transfer were still extensive. Restraints dealt with every aspect of technology critical to development of communication satellite capabilities and production techniques, as well as equipment and manufacturing processes pertaining to satellites and launch vehicles or components thereof. See Lorenza Sebesta, *The Availability of American Launchers and Europe's Decision 'To Go It Alone,'* ESA HSR-18 (Noordwijk, Netherlands: ESA Publications Division, September 1996).

[109] For an overview of this "technology gap" and U.S. policy on technology transfer to Europe from 1964 to 1972, see Lorenza Sebesta, *The Availability of American Launchers and Europe's Decision 'To Go It Alone,'* ESA HSR-18 (Noordwijk, Netherlands: ESA Publications Division, September 1996). Also, see Lorenza Sebesta, "The Politics of Technological Cooperation in Space: U.S.-European Negotiations on the Post-Apollo Program," *History and Technology* 11 (1994): 319-326.

[110] ELDO was disbanded in 1972.

[111] John M. Logsdon, "U.S.-European Cooperation in Space Science: A 25-Year Perspective," *Science* 223, 4631 (1984): 11-16.

[112] Eligar Sadeh, "International Space Cooperation," in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[113] W. D. Kay, *Defining NASA: The Historical Debate over the Agency's Mission* (Albany, New York: State University of New York Press, 2005).

[114] In the 1970s and 1980s, NASA commissioned a number of studies that undertook a comprehensive economic analysis and impact of the civil space program on the national economy. NASA officials hoped that the results of the studies would show very robust impacts on the economy, legitimizing the benefits from the investment in space. See Henry R. Hertzfeld, "Space as an Investment in Economic Growth," in Logsdon, John, ed., *Exploring the Unknown, Selected Documents in the History of the U.S. Civil Space Program, Volume III: Using Space* (Washington, DC: NASA History Office, 1998).

[115] Molly K. Macauley, "Economics of Space, in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002); *Final Report: The Economic Impact of NASA R&D Spending*, prepared for NASA, contract NASW-2741, Chase Econometric Associates, April 1976; Short and Long-Term Impacts of NASA R&D Spending on the Economy, February 9, 1976 [unpublished manuscript]; *Final Report: The Economic Impact of NASA R&D Spending*, prepared for NASA, contract NASW-2741, Chase

Econometric Associates, April 1975; *Economic Impact of Stimulated Technological Activity*, prepared for NASA, contract NASW-2030, Midwest Research Institute, November 22, 1971.

[116] Report of the Comptroller General of the United States, NASA Report May Overstate The Economic Benefits Of Research and Development Spending, October 18, 1977.

[117] Ibid.

[118] National Science Foundation, *Science and Engineering Indicators* (Washington, DC: United States Government Printing Office, 2000); and Henry R. Hertzfeld, “Space as an Investment in Economic Growth,” in Logsdon, John, ed., *Exploring the Unknown, Selected Documents in the History of the U.S. Civil Space Program, Volume III: Using Space* (Washington, DC: NASA History Office, 1998).

[119] *The Economic Impact of NASA R&D Spending*, prepared for NASA, contract NASW-3346, Chase Econometric Associates, April 15, 1980.

[120] *Research Funding as an Investment: Can We Measure the Returns? A Technical Memorandum* (Washington, DC: United States Congress, Office of Technology Assessment, OTA-TM-SET-36, April 1986).

[121] Henry R. Hertzfeld, *Space Economic Data*, United States Department of Commerce, Office of Space Commercialization, December 2002.

[122] Molly K. Macauley, “Economics of Space, in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[123] Henry R. Hertzfeld, “Measuring the Economic Returns from Successful NASA Life Sciences Technology Transfers,” *Journal of Technology Transfer* 27:4 (2002).

[124] Molly K. Macauley, “Economics of Space, in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[125] M. A. Holman, *The Political Economy of the Space Program* (Palo Alto, California: Pacific Books, 1974).

[126] Economic multipliers refers can be controversial because the initial public investment must originate somewhere, usually from the private sector. Thus, the public project, even with superb multipliers, may or may not be better than a private investment based on competitive market and economic factors. David Livingston, “Winning the Public’s Support for Space Development Programs and Funding,” Space Technology and Applications International Forum (STAIF) 2005, Albuquerque, New Mexico.

[127] *Research Funding as an Investment: Can We Measure the Returns? A Technical Memorandum* (Washington, DC: United States Congress, Office of Technology Assessment, OTA-TM-SET-36, April 1986).

[128] *Final Report: The Economic Impact of NASA R&D Spending*, prepared for NASA, contract NASW-2741, Chase Econometric Associates, April 1976; and *Final Report: The Economic Impact of NASA R&D Spending*, prepared for NASA, contract NASW-2741, Chase Econometric Associates, April 1975.

[129] In 1988, the Midwest Research Institute under contract to the National Academy of Public Administration performed an analysis that replicated a 1971 Midwest Research Institute study that showed a 9 to 1 cost benefit ration for NASA R&D programs. This finding held up to sensitivity analysis, however, NASA did not release the study as it was subject to many technical economic qualifications. See Henry R. Hertzfeld, “Space as an Investment in Economic Growth,” in Logsdon, John, ed., *Exploring the Unknown, Selected Documents in the History of the U.S. Civil Space Program, Volume III: Using Space* (Washington, DC: NASA History Office, 1998).

[130] *The Economic Impact of NASA R&D Spending*, prepared for NASA, contract NASW-3346, Chase Econometric Associates, April 15, 1980.

[131] *Measuring the Impact of NASA on the Nation’s Economy*, NASA Office of Special Studies, September 1990 [unpublished report]. Also, see Jerome E. Schnee, Space Program Impacts Revisited, *California Management Review* 20:1 (1977).

[132] United States Office of Management and Budget, “Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,” Circular No. A-94, October 29, 1992.

[133] Molly K. Macauley, “Economics of Space, in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[134] See “Legacy of Apollo: Enduring Gifts to Humanity.” This documentary is produced by the Connell Whittaker Group, LLC. The documentary takes a new look at how the Apollo Program radically reinvaded the global community, a new economy, and an environmental consciousness. Also, see David Livingston, “Winning the Public’s Support for Space Development Programs and Funding,” Space Technology and Applications International Forum (STAIF) 2005, Albuquerque, New Mexico. David Livingston is the creator of radio interview show called The Space Show. Livingston has interviewed over three-hundred personalities in the space community. One common theme among these individuals is that Apollo was what inspired them to pursue space-related careers,

including those aimed at space commercial development. See www.thespaceshow.com (accessed September 13, 2006).

[135] NASA inherited many of its programs from the Department of Defense, and inherited the same set of industrial contractors that supported the space and missile business that began in the 1950s. See Stephen B. Johnson, “History of Space Business,” in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[136] Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore: Johns Hopkins University Press, 1993).

[137] The information in this Table is taken from Stephen B. Johnson, “History of Space Business,” in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[138] *Measuring the Impact of NASA on the Nation’s Economy*, NASA Office of Special Studies, September 1990 [unpublished report].

[139] *Research Funding as an Investment: Can We Measure the Returns? A Technical Memorandum* (Washington, DC: United States Congress, Office of Technology Assessment, OTA-TM-SET-36, April 1986). For a history of patents as they apply to NASA, see Sylvia K. Kraemer, “Federal Intellectual Property Policy and the History of Technology: The Case of NASA Patents,” *History and Technology* 17 (2001).

[140] M. A. Holman, *The Political Economy of the Space Program* (Palo Alto, California: Pacific Books, 1974).

[141] Henry R. Hertzfeld, *The Economic Impact of Civilian Space Research and Development Expenditures*, National Academy of Sciences, National Research Council Colloquium: The Role of Federal R&D, November 21, 1985.

[142] Ibid.

[143] Richard S. Rosenbloom, The Transfer of Space Technology, report submitted to the Committee on Space, American Academy of Arts and Sciences, NASA Grant NsG-253-62, March 1965.

[144] Martin D. Robbins and et. al., “Mission-Oriented R&D and the Advancement of Technology: The Impact of NASA Contributions,” Denver Research Institute, May 1972.

[145] Joan Lisa Bromberg, *NASA and Space Industry* (Baltimore, Maryland: The Johns Hopkins University Press,1999).

[146] McDougall, Walter A. …*The Heavens and the Earth, A Political History of the Space Age* (Baltimore, Maryland: The Johns Hopkins University Press, reprinted in 1997).

[147] Ibid.

[148] Donald C. Elder, “Something of Value: Echo and the Beginnings of Satellite Communications,” in Butrica, Andrew J., ed., *Beyond the Ionosphere: Fifty Years of Satellite Communications* (Government Printing Office: Washington, DC, NASA History Office, 1997).

[149] David J. Whalen, “Billion Dollar Technology: A Short Historical Overview of the Origins of Communications Satellite Technology, 1945-1965,” in Butrica, Andrew J., ed., *Beyond the Ionosphere: Fifty Years of Satellite Communications* (Government Printing Office: Washington, DC, NASA History Office, 1997).

[150] Stephen B. Johnson, “History of Space Business,” in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[151] Advances in telecommunications satellite technology are due to a number of leading commercial developers, and contributions that include not only NASA, but also the Department of Defense, National Science Foundation, universities, research laboratories, and the Jet Propulsion Laboratory. Leading developers included: Ball Aerospace, Fairchild, Hughes Aircraft, Lockheed-Martin, TRW, and Ford Aerospace (now Space Systems Loral). See Joseph N. Pelton, “The History of Satellite Communications,” in Logsdon, John. ed., *Exploring the Unknown, Selected Documents in the History of the U.S. Civil Space Program, Volume III: Using Space* (Washington, DC: NASA History Office, 1998).

[152] Paul D. Lowman, “T Plus Twenty Five Years: A Defense of The Apollo Program,” *Journal of British Interplanetary Sciences* 49 (1996); and F. Douglas Johnson and et. al., “NASA Tech Brief Program: A Cost Benefit Evaluation,” Denver Research Institute, May 1977.

[153] See http://www.sti.nasa.gov/tto/apollo.htm (accessed June 5, 2006). This list is just an example and there are additional spinoffs linked to Apollo.

[154] See, for example, “Legacy of Apollo: Enduring Gifts to Humanity,” Connell Whittaker Group, LLC [video produced documentary].

[155] http://klabs.org/richcontent/Misc_Content/AGC_And_History/AGC_History.htm (accessed September 15, 2006), NASA Office of Logic Design.

[156] Two IC-based AGCs were designed, the Block I AGC for the unmanned test missions, and the improved Block II AGC for the manned launches.

[157] http://www.ieee-virtual-museum.org/collection/event.php?taid=&id=3457010&lid=1 (accessed 15 September 2006).

[158] The Massachusetts Institute of Technology used as much as 30% of the total world output of ICs for the development of the AGC.

[159] See http://klabs.org/richcontent/Misc_Content/AGC_And_History/AGC_History.htm (accessed September 15, 2006).

[160] W. D. Kay, *Defining NASA: The Historical Debate over the Agency's Mission* (Albany, New York: State University of New York Press, 2005).

[161] Singling out the effect of government influence on the products' markets can also be difficult. For example, TANG, Velcro, and Teflon are all frequently cited as spinoffs from the Apollo program, but they were actually developed before the Apollo program began. However, the program might have refined these products or brought them to broader attention and thus, expanded commercial markets. Whatever the case, these issues further confound the effort to use spinoffs as a justification for investing in space. See Molly K. Macauley, "Economics of Space, in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[162] Brevard County Planning Department, *The Impact of Apollo 11 on Brevard County, Florida* [undated document].

[163] Ibid.

[164] Molly K. Macauley, "Economics of Space, in Sadeh, Eligar, ed,. *Space Politics and Policy: An Evolutionary Perspective* (The Netherlands: Kluwer Academic Publishers, 2002).

[165] Willard I. Zangwill, "Top Management and the Selection of Major Contractors at NASA," *California Management Review* 12: 1 (1969).

[166] "The Intangible Benefits of Space Programs to Geographic Regions," December 18, 1963 [unpublished draft paper]; and "Recent Economic Impact Research," Memorandum for Mr. Finger, Irwin P. Halpern, Director, Policy Staff, NASA, January 2, 1968.

[167] Lloyd S. Swenson, "The Fertile Crescent: The South's Role in the National Space Program," *Southwestern Historical Quarterly* LXXI (3) (1968).

[168] P. Dow, "Sputnik Revisited: Historical Perspectives on Science Reform," prepared for the symposium, Reflecting on Sputnik: Linking the Past, Present, and Future of Educational Reform (Washington, DC: October 4, 1997).

[169] National Science Foundation, *Science and Engineering Indicators* (Washington, DC: United States Government Printing Office, 2000).

[170] P. Dow, "Sputnik Revisited: Historical Perspectives on Science Reform," Reflecting on Sputnik: Linking the Past, Present, and Future of Educational Reform (Washington, DC: October 4, 1997).

[171] "The Apollo Education Initiative: Origins, Activities, and Results" (Washington, DC: Space Policy Institute, George Washington University, June 1990).

[172] *Final Report of the Commission on the Future of the United States Aerospace Industry*, November 2000.

[173] National Science Foundation, *Science and Engineering Indicators* (Washington, DC: United States Government Printing Office, 2002).

[174] Ibid.

[175] *Final Report of the Commission on the Future of the United States Aerospace Industry*, November 2000.

[176] National Science Foundation, *Science and Engineering Indicators* (Washington, DC: United States Government Printing Office, 2000).

[177] W. Henry Lambright, "Using Universities: The NASA Experience," Public Policy 1972; W. H. Kohl, "The Potential Influence of NASA's Long-Range Technological Needs on the Restructuring of University Engineering Curricula," Advisory Council Meeting, October 2-3, 1969.

[178] James E. Webb, *Space Age Management: The Large-Scale Approach* (New York, New York: McGraw-Hill Book Company, 1969).

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