Key Policies to Success of NASA's Commercial Crew Program

Considering Lessons Learned from Past Public to Private Function Transfers

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Executive Summary

The National Aeronautics and Space Administration's (NASA's) goal for commercial human spaceflight to low Earth orbit (LEO) is to stimulate a robust, vibrant, and profit-making commercial enterprise with many providers and a wide range of private and public users. A successful human space transportation system will strengthen the International Space Station (ISS) program, enable NASA to focus on exploration beyond LEO, potentially reduce the cost of transporting cargo and crew to and from LEO, and contribute to the U.S. economy. NASA's Commercial Crew Program (CCP) is a significant step toward realizing this goal. This paper considers a number of policies, as identified in an ISS LEO Commercialization workshop held at NASA Headquarters in December 2014. The authors prioritize these policies based on how well they are able to develop and promote commercial spaceflight to and from LEO. Further, this paper selects two top policies. The first would extend the ISS Intergovernmental Agreements (IGAs), Implementing Arrangements, and Memorandums of Understandings (MOUs) beyond 2020. The second would create a roadmap to help forecast NASA needs for LEO as it transitions from a supply- to a demand-side supporter.

This paper relies on lessons from history to shape policy guidance. A number of case studies in which the U.S. government attempted to develop private capacity for a particular service were analyzed and compared to NASA CCP:

- Privatization of the United States Airmail
- Tennessee Valley Authority (TVA)
- Atomic Energy Commission's (AEC's) Power Reactor Demonstration Program (PRDP)
- Federal Aviation Administration's (FAA's) Supersonic Transport (SST) program.
- Privatization of the United States Enrichment Corporation (USEC)

While each case study has its own unique issues and context, the importance of perceived market demand is prevalent. Moreover, the longer the government supports demand within a market, the more likely the market fails to become self-sustaining. However, if government support is withdrawn too soon before new commercial firms mature, private demand may not be sufficient to sustain the market.

Introduction and Background

On July 21, 2011, Space Shuttle Atlantis safely returned from what was the final Space Shuttle mission.[1] For over three decades, the government owned and operated Space Shuttle, the only U.S. heavy lift, crew-rated vehicle, to transport astronauts to and from low Earth orbit (LEO). With no crew-rated vehicle to replace the Space Shuttle, NASA now relies on the Russian Soyuz to transport NASA astronauts to and from LEO. Within NASA, there was much debate about Shuttle's replacement and whether that vehicle would be owned and operated by NASA. Ultimately, NASA decided to develop the next generation of LEO vehicles through the Commercial Crew Program (CCP). A program which strives to create an environment where NASA no longer procures LEO human spaceflight capabilities but invests in industry-developed, -owned, and -operated vehicles. This approach is a major break from NASA's previous approaches to human spaceflight.

In the United States, commercial industry plays an integral role in LEO. From satellites to launch vehicles, American companies enable both private and public endeavors for economic gain and exploration. While NASA has historically contracted out work for major space systems development, such as the Saturn V rocket and the Space Shuttle, NASA is now looking to purchase commercially owned human spaceflight systems. This arrangement means that commercial companies will also be able to sell their human spaceflight services to non-governmental buyers.

Established in 2006, NASA CCP is a collaborative effort with private industry firms to develop next-generation human spacecraft for LEO transportation. CCP's goal is to end the United States' current lack of capability to transport astronauts to and from ISS and LEO by 2017.[2] Promotion of private-public partnerships to advance human, cargo, and satellite commercial launch capabilities is a key theme of the White House's 2013 National Space Transportation Policy.[3] CCP builds off the success of the Commercial Orbital Transportation Services program (COTS). COTS was a two-stage program in which NASA invested approximately $800 million from 2006 to 2012 to help industry develop, demonstrate, and eventually provide cargo delivery capability to ISS.[4] COTS produced two successful providers, Orbital ATK and SpaceX, to replace cargo capabilities lost from the retirement of the Space Shuttle. CCP engages private industry through Space Act Agreements that NASA uses to invest in industry spacecraft development. In late 2014, NASA awarded Boeing and SpaceX with fixed price contracts worth a total of $6.8 billion to transport NASA astronauts to and from ISS from 2017 to 2023.[5] Without the success of CCP, NASA will be left with difficult options, including the continuation of purchases of Russian Soyuz flights and a backing out on its ISS commitments.

[1] (Mansfield, C. L. 2015)
[2] (Commercial crew program 2014)
[3] (Fact sheet: 2013 national space transportation policy 2013)
[4] (Turnbough, L. 2012)
[5] (Siceloff, S. 2014)

In pursuit of CCP's goals, NASA held a workshop in December 2014 to discuss potential policies.[6] The purpose of the workshop was to start a dialog between government agencies, industry, and think tanks on creating a thriving commercial marketplace in LEO over the next decade. Below is a list of the general recommendations for the United States government proposed by workshop participants:

1. Extension of current Intergovernmental Agreements (IGAs), Implementing Arrangements, and Memorandums of Understanding (MOUs) to allow activities beyond ISS 2020.
2. Roadmap to forecast NASA needs for LEO (Transition from a supplier to a demand-side supporter)
3. Policy for commercial habitat/module on and beyond ISS
4. Address indemnification, liability in space
5. Increase transparency on what's available on ISS and how projects are prioritized
6. ISS upgrades for commercial opportunities
7. Establish LEO as an economic development zone
8. Expand other types of contractual arrangements (Space Act Agreements)
9. Streamline ISS processes for commercial users
10. Spaceflight participant policy for non-NASA crew
11. Develop a LEO regulatory authority

In this paper, the authors analyze and rank these policy recommendations based on lessons learned from the historical analogies, which are discussed in the next section. The first-ranked policy supports the extension of all IGAs, Implementing Arrangements, and MOUs pertaining to ISS beyond 2020 to provide a platform for commercial actors to participate and develop services in LEO. The second-ranked policy calls for creating a roadmap for NASA to forecast future needs for LEO. These recommendations are presented in detail in the Policy Statement section.

This paper seeks to provide the reader with a general background of current and past initiatives while also utilizing historical analogies that provide guidance on viable policies. As a result, the authors seek to contribute more than just a broader understanding of space commercialization but how past government commercialization and privatization efforts outside of space can inform NASA efforts today.

[6] (Gerstenmaier, W., et. al. 2014)

Historical Analogies

Lessons learned from historical analogies inform the paper's two policy proposals. A number of case studies in which the U.S. government attempted to develop private capacity for a particular service were analyzed and compared to NASA CCP. While each case study has its own unique issues and context, the importance of perceived market demand is prevalent. Moreover, the longer the government supports demand within a market, the more likely the market fails to become self-sustaining. However, if government support is withdrawn too soon before new commercial firms mature, private demand may not be sufficient to sustain the market. The authors prioritize policy recommendations from the LEO workshop based on their ability to increase or develop market demand in LEO.

Case Studies Considered

The case studies that the authors consider in this paper illustrate successes and failures of government transfer of functions to the private sector. The five case studies are as follows:

1. Privatization of the United States Airmail (1926-1936)
2. Tennessee Valley Authority (1933-1959)
3. Atomic Energy Commission's Power Reactor Demonstration Program (1955-1963)
4. Federal Aviation Administration's SuperSonic Transport program (1963-1971)
5. Privatization of the United States Enrichment Corporation (1992-1998)

A detailed overview and analysis of each case study is available in the Appendix.

When considering these historical analogies, the authors seek to consistently answer a series of questions. These questions include:

1. Under what conditions did some of these government to commercial function transfers occur?
2. What facets of these programs were successful and/or unsuccessful?
3. What regulatory environments led to successful public-private partnerships?

Relation to CCP and LEO

The case studies the authors consider in this paper are past United States government efforts transfer a public function to the private sector. CCP is a NASA-facilitated effort to replace human spaceflight capabilities that were previously provided by the Space Shuttle. While each case study is unique, this paper's objective is to take lessons learned in the broad context of U.S. policy and provide policy recommendations for CCP. At its core, CCP seeks to create a commercial service is also the central objective of these case studies.

Lessons Learned

Below are the salient points from each case study on lessons learned. The Appendix offers a detailed background and analysis of each case study.

Privatization of the United States Airmail

- While public-private partnerships may not originally be cost-effective, they may achieve the near-term policy goals of the government and allow time for private demand to arise.

Tennessee Valley Authority (TVA)

- The longer the federal government insulates a program from market forces, the more it risks creating a subsidy-dependent program whose costs and debts increase and whose structure becomes institutionalized and less capable of adapting to regulatory and industry changes.
- Federal investment may yield immediate returns in a public-private partnership.

Atomic Energy Commission's Power Reactor Demonstration Program (PRDP)

- If the level of perceived market demand for a future product or service is favorable enough, companies will invest and bare risks with or without government subsidies or protection.
- Research and development efforts should not be confused or mixed with the demonstration of full-scale commercial feasibility of a new system.

Federal Aviation Administration's Supersonic Transport (SST) program

- Drive for national prestige can lead to ignorance of market realities.

Privatization of the United States Enrichment Corporation (USEC)

- Despite government subsidies and improved internal efficiencies, there has to be strong market demand and ability to innovate in order for companies to succeed.

Summary and Conclusions for CCP

The primary lesson from all of the case studies is that perceived and actual market demand are major drivers of success or failure. For companies to accept risk and invest in public-private partnerships, companies have to sense the potential for profit. These case studies show that government can be a major source of demand. However, government must determine when to shield or expose companies to market forces. In the case of CCP, government demand is necessary for commercial firms to potentially develop business plans. Therefore, the authors seek to stabilize government demand for human spaceflight in LEO via these proposed policies.

Policy Statement

The Policy Goal

The goal of these policy recommendations is to make CCP successful. CCP is designed to facilitate the development of a U.S. commercial crew space transportation capability to and from ISS and LEO. The program goal is to achieve the following criteria for transport to and from LEO:[7]

- Safe
- Reliable
- Cost-effective

Certainly, CCP depends on a number of factors and milestones. The most important of these is safety. Standing internal and external review panels over CCP ensure NASA's safety requirements are met. Crewed flight test of Boeing and SpaceX safety systems will not begin until 2017.[8] Therefore, this paper presents policy recommendations on the top policy actions that NASA should take in the near-term to ensure the long-term success of CCP. The authors use CCP's goal to derive policies from and a list of recommendations gathered from a December 2014 NASA LEO Workshop.

As stated in the previous section, market demand is a major driver for companies to accept risk and invest in public-private partnerships. Therefore, these policy recommendations seek to offer an approach that both stabilizes government demand for a predictable timeline and opens LEO to private entities. These private entities will service and operate onboard ISS or work with future commercially developed habitats that require the CCP services.

Recommendations

The top policy recommendations are prioritized, in order, below:

Policy 1: Extension of Current Intergovernmental Agreements (IGAs) to Allow Activities beyond ISS 2020

The exact language on this recommendation for the December 2014 LEO workshop stated that the US government should focus on "Extension of current IGAs to allow activities beyond ISS." This paper interprets IGA's to also encompass MOUs and Implementing Arrangements, which are current diplomatic instruments that are embedded in the ISS agreements. This recommendation, as well as a majority of subsequent recommendations, assumes ISS operability beyond 2020. However, the current ISS international agreements are only in effect until 2020. While in early 2014, NASA declared a desire to extend the ISS agreements to 2024, an actual

[7] (Statement of William H. Gerstenmaier 2015 pg. 1)
[8] (Harwood, William 2015)

agreement with existing partners remains unfinished. NASA can extend ISS's lifespan by renewing the agreements with existing partners. However, this does not mean that other potential partners should be excluded if the opportunity arises.

The current CCP Commercial Crew Transportation Capability (CCtCap) contracts, awarded to Boeing and SpaceX in 2014, can support ISS crew transport operations through 2023 if Boeing and SpaceX fulfill the CCtCap contractual obligations.[9] Therefore, this paper proposes an official extension of ISS to at least 2024 with the possibility of extending consideration towards ISS operations until 2028. The short-term market demand for LEO human spaceflight from now to 2024 appears primarily dependent on government demand for crew transportation to ISS. Already, Boeing and SpaceX business plans center on the ability to deliver missions to and from ISS through 2023. Removing this platform before other sources of demand for crew transportation emerge could lead to market withdrawal by these commercial companies. Thus, ISS not only serves as a vital national laboratory for NASA and private industry, but provides a platform for companies to mature technologies in a microgravity environment. For example, Bigelow Aerospace is planning to deploy a test crew habitation module in late 2015. These technologies may create a new source of sustainable demand for launch providers like Boeing and SpaceX to satisfy crew demand beyond ISS.

Policy 2: Roadmap to Forecast NASA Needs for LEO (Transition from a Supply- to a Demand-Side Supporter)

NASA presented a broad outline of its goals to achieve sustained economic activity in LEO in its December 2014 workshop. While NASA cannot predict commercial innovations, NASA should be able to lay out a detailed roadmap for LEO activities. Such a roadmap could include the following:

- Specific crew and supply transportation needs to and from ISS and LEO through 2024 that expands upon the broader language stated in the current NASA Strategic Plan.[10]
- A NASA and the Center for the Advancement of Science in Space (CASIS) implementation plan for increasing ISS U.S. module utilization for commercial use. This could include a proposed timeline that slowly allocates more ISS utilization in U.S. modules for commercial activities.
- NASA crew transportation needs for LEO missions beyond ISS.

This plan will certainly have to evolve with changing priorities and technological capabilities. However, any NASA forecast on its future demand as a buyer of commercial services provides industry market clarity. If NASA can establish even a crude estimate of its future demand as a buyer of commercial services, it will be able to offer industry important data to clarify and develop business plans. Such a roadmap would also demonstrate NASA's commitment to

[9] (Statement of William H. Gerstenmaier 2015)
[10] (NASA Strategic Plan 2014)

removing itself as a provider of launch services to and from in LEO. The roadmap should be widely advertised and promoted by NASA leadership. Furthermore, the roadmap process should be open to industry input and feedback to garner buy-in and ensure that the roadmap document actually clarifies and improves the market outlook for LEO. The LEO workshop could serve as a model for future events to facilitate this conversation between NASA and industry.

Ownership of Each Policy

Policy 1: Extension of Current IGAs to Allow Activities beyond ISS 2020

The following organizations share ownership of Policy 1, extension of current IGAs to allow activities beyond ISS 2020:

- **NASA Human Exploration and Operations (HEO) Mission Directorate:** As the primary owner and executor of NASA human spaceflight activities, NASA HEO must ensure it can meet any obligations associated with the extension of international endeavors in LEO. HEO would have to prepare itself for the potential loss of hardware and operations support if any international partners withdraw from ISS.

- **NASA Office of International and Interagency Relations (OIIR) Human Exploration and Operations Division (HEOD):** HEOD supports policy direction and interest on international issues and relationships with current and prospective international partners.[11] HEOD also drafts and negotiates international agreements for new space cooperation, and supports ongoing interaction with international partners. Currently, ISS agreements allow for any nation to withdraw from ISS with only one year's notification.

Policy 2: Roadmap to Forecast NASA Needs for LEO (Transition from a Supply- to a Demand-Side Supporter)

The following organizations share ownership of Policy 2, development of a roadmap to forecast NASA needs for LEO:

- **NASA HEO Mission Directorate:** HEO provides the Agency with leadership and management of NASA space operations related to human exploration in LEO.[12] Specifically, the Commercial Spaceflight Development Division facilitates any new space act agreements or contracts related to further commercial development related to cargo, crew, or habitat that NASA would like to foster or transfer over to private industry.

[11] (Bowie, M. 2011)
[12] (Wiles, J. 2015)

- **NASA Space Technology Mission Directorate (STMD):** STMD is responsible for developing the crosscutting, pioneering, new technologies and capabilities needed by the agency to achieve its missions.[13]

With these two policies, NASA would establish a baseline for LEO human spaceflight demand for LEO that would last for the next decade. As a result of these policy actions, the Commercial Crew Transportation Capability contract could fully utilize Boeing and SpaceX systems through 2023.[14] Basing their plans on this demand, these companies could develop technologies that would reduce costs and create new interest in human spaceflight. Additionally, more flights may translate into lower costs that would create a more fertile environment for commercial development. Commercial development increases the probability that long-term, safe, reliable, and cost-effective commercial options for LEO transportation will be available for NASA to purchase as needed.

[13] (Hall, L. 2013)

[14] (Statement of William H. Gerstenmaier 2015)

Argument

The overarching goal of the policy recommendations in this paper is to help NASA to transfer successfully an historically federal function, human spaceflight and cargo transportation to and from LEO, to the private sector. From a list of policies identified in NASA's LEO workshop, two policies stand out in terms of their near-term implications for the success of CCP and draw upon historical analogies, which the authors of this paper detail in the Appendix.

These policies include (1) the extension of current IGAs, MOUs, and Implementing Arrangements between ISS partners beyond the 2020 expiration of these agreements and (2) development of a roadmap to lay out milestones and goals for NASA LEO activities. The top policy goal is extension of these agreements between ISS partners. Subsequent sections describe the rationale behind selection and prioritization of these and other goals.

Policy 1: Extension of ISS IGAs beyond 2020

In its current state, the ISS IGA and bilateral agreements between the U.S. and ISS partners are scheduled to expire in 2020. ISS partners include NASA, Roskosmos, the European Space Agency (ESA), the Japanese Aerospace Exploration Agency (JAXA), and the Canadian Space Agency (CSA). Three of five ISS partners have expressed interest in extending ISS operations beyond 2020. Those ISS partners include NASA, Roskosmos, and CSA.[15,16,17] Prior to February 2015, the U.S. was the only country that had announced a willingness to extend operations beyond 2020. While the White House and NASA have expressed interest in continuing operations until 2024, the U.S. Congress has not yet shown interest in appropriating funds for extended operations. In April 2015, CSA also indicated a willingness to extend its participation in ISS beyond 2020.[18]

In early 2015, the Roskosmos Science and Technical Council convened to discuss the future of Russian human spaceflight, and favored continued use of ISS until 2024.[19] In February 2015, Russia announced that it is willing to extend operations to 2024. Thereafter, Russia has proposed undocking Russian-owned ISS elements from ISS. Space News reports, "Roscosmos characterized its proposed ISS defection as a first step in a broader strategic plan that would see Russia land cosmonauts on the moon in the 2030 timeframe."[20] Russian ISS elements, as outlined in Article 3 of the ISS MOU between NASA and Roskosmos, includes one Service Module, two Life Support modules, two Docking Compartments, one Universal Docking

[15] (Achenbach, J. 2014)
[16] (Svitak, A. 2015)
[17] (de Selding, P. B. 2015)
[18] Ibid.
[19] (Clark, S. 2015)
[20] ("Good news from Russia")

Module, one Science Power Platform, and several other elements.[21] Debate exists about the implications of Russia's proposed undocking from ISS.

While it is not clear what modules Russia intends to undock from ISS in 2024, the potential loss of thrust capabilities are of greatest concern. These capabilities include Progress cargo ships, which, when docked with ISS, use engine pulses to change the orbit of ISS.[22] The Zvezda module, one of the original modules of ISS, also provides ISS with thrust. These cargo ships and modules enable ISS operators to maintain an altitude of 350 to 460 km, which is necessary to counter atmospheric drag and de-orbiting of the orbital facility.[23] Without regular reboosts, ISS may experience an irreversible orbital decay within one year. In addition, these thrusting capabilities enable ISS operators to avoid debris by adjusting the orbit of ISS. Without these capabilities, ISS operators would be unable to perform these debris avoidance maneuvers.[24]

Whereas the remaining ISS partners, ESA and JAXA, are presently uncommitted to continuing involvement in ISS after 2020, none of these ISS partners have publicly expressed interest in undocking ISS elements. An article published to Spaceflight Now in February 2015 provides a summary of current discussions by these partners.

> [ESA] plans to put forward a proposal for more space station funding from European member states at their next high-level budget meeting in 2016 … Naoki Okumura, president of [JAXA], said in October that Japan would decide by 2016 whether to commit to more years of space station operations. For all the space station partners — but particularly ESA and JAXA — finding money to pay for the program after 2020 may depend on cutting the cost of operating the complex.[25]

In addition to these discussions, it is important to consider the current legal framework to which ISS partners have agreed. Articles 6 and 9 of the ISS IGA of 1998 outline ownership and utilization of ISS elements, including the sale or bartering of ISS elements to partner states. In Article 9(4) of the ISS IGA, ISS partners are also encouraged to avoid causing harm to other ISS partners.[26] Undocking of essential ISS elements, e.g., the Zvezda module, may cause harm to other ISS partners by reducing the debris avoidance and orbital reboosting capabilities of ISS. This rationale is outlined in Article 28(3)(a) of the ISS IGA 1998 in which the U.S. and Canada identify several Canadian-owned ISS elements that are "essential." These essential elements are

[21] (ISS IGA 1998)
[22] (Pappalardo, J. 2007)
[23] (Leone, D. 2015)
[24] (Oberg, J. 2015)
[25] (Clark, S. 2015)
[26] (ISS IGA 1998)

to be transferred to the United States if Canada withdraws from the ISS IGA. Article 28(1) also states that partner states may withdraw from the ISS if they provide one year's written notice.[27]

Extension of the current ISS IGAs beyond 2020 provides NASA commercial crew partners with a platform from which they can build sustainable business models for a post-ISS LEO. If ISS partners withdraw from ISS before commercial companies achieve a minimal capability in LEO, and essential ISS elements are undocked or disabled, ISS may no longer be a viable orbital platform. This may lead to significant challenges for commercial companies before demand has been realized.

The authors consider extension of the ISS agreements to be a top priority because it influences all other priorities identified during the workshop. Without ISS as a destination for commercial companies, demand for crewed launches to and from LEO may fade.

Policy 2: Roadmap to Forecast NASA Needs for LEO (Transition from a Supply- to a Demand-Side Supporter)

NASA has developed and is currently implementing a roadmap for Commercial Cargo and Crew. This roadmap provides an overview of near- and long-term milestones and programs, spanning past, current, and future CCP activities (see Figure 1).[28]

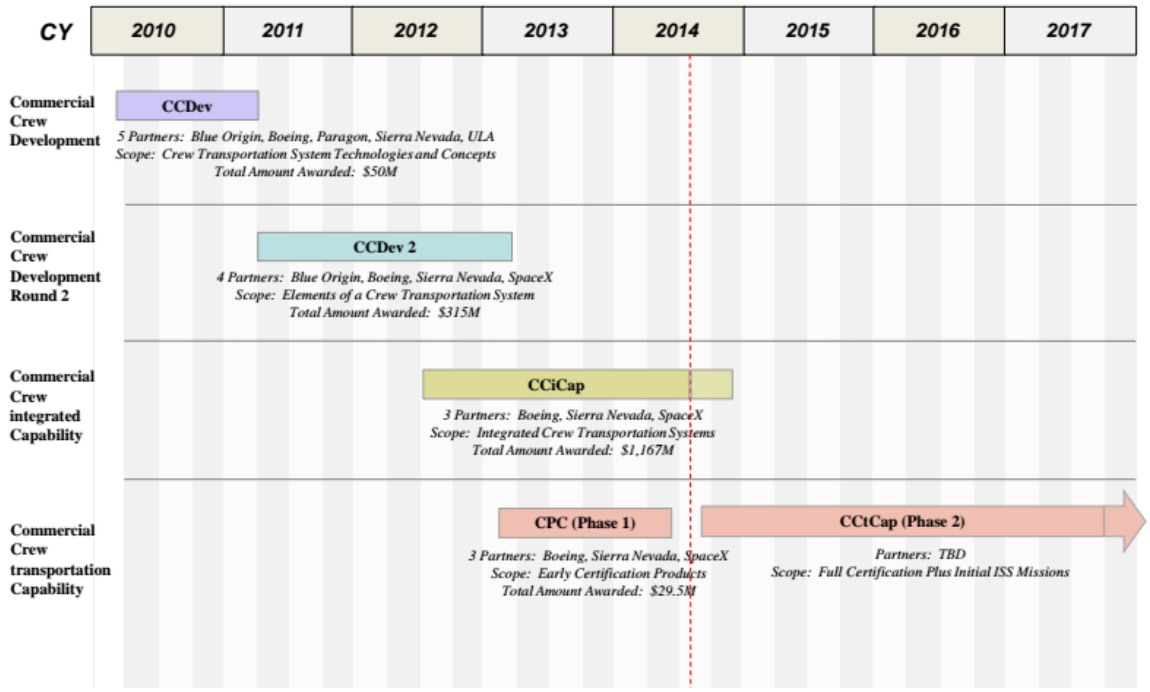

Figure 1: NASA Roadmap for Commercial Crew and Cargo

[27] Ibid.

[28] (McAlister 2014)

On this roadmap, CCiCap is in the implementation phase, and its contract awardees, SpaceX and Orbital ATK are carrying out separate contracts to resupply ISS with cargo. CCtCap is the next step in NASA's CCP roadmap, and it is currently in the formulation phase. NASA selected SpaceX and Boeing as the prime contractors for the CCtCap contract. These activities and milestones outline commercial capabilities, cargo, and crew, and largely center on re-supply and transportation to and from ISS.

Whereas the CCP roadmap outlines milestones for Commercial Cargo and Crew, it does not take into consideration an ISS with potentially reduced capabilities due to ISS partner withdrawal. Moreover, it does not take into account the possibility of a post-ISS scenario in which commercial companies no longer have access to ISS as an orbital platform. To ensure this option, NASA should develop and implement a roadmap with ISS partners and commercial companies that projects government demand in LEO.

Comparison of Top Priorities

The two policies outlined in this paper share similarities but differ in a number of ways. Both policies share the overarching goal of a successful CCP and the eventual transfer of a federal function in LEO to the private sector. Further, both policies are contingent on dialog and agreement among several stakeholders, including ISS partners, commercial cargo and crew companies, the White House, the U.S. Congress, and the U.S. Department of State.

These policies diverge from one another in that Policy 1 centers on the availability of hardware (e.g., ISS essential elements), operations and maintenance, and funding for ISS. Policy 2 provides a clear path to expand the LEO market by extending the ISS program. Policy 1 is fundamentally an issue of hardware and international agreement, whereas Policy 2 is primarily a plan of actions required to realize the commercial potential of an extended ISS orbital facility.

Policies 1 and 2: Strengths, Weaknesses, Opportunities, and Threats

Each of the top policies that the authors recommend in this document have strengths, weaknesses, opportunities, and threats. This section provides further insight into these issues and takes into consideration historical case studies (see Appendix).

Strengths

Extension of ISS IGAs beyond 2020 will create a stable platform for commercial companies. With several notable exceptions (e.g., current CCP partners), commercial firms (and their investors) have thus far been unwilling to invest resources in human spaceflight. The extension of ISS beyond 2020 provides the type of stability that should attract future investment in LEO and commercial use of ISS. This strength of the ISS IGA extension bares an historical resemblance to the U.S. Airmail program. In the 1920s, the United States Postal Service (USPS) continued to work with commercial airlines as the main contractor despite the fact that the

program was not economically profitable at the time. This stable demand allowed airlines time to develop and attract private demand.

Development of a roadmap to forecast NASA needs in LEO clarifies government demand. By clarifying the demand, NASA will provide a stable environment for commercial investment in LEO. During the U.S. Airmail effort, the United States set a clear goal of nationwide airmail routes for USPS deliveries. This goal provided commercial airlines with an idea of government demand.

Weaknesses

If the U.S. reaches an agreement with ISS partner states on an extension of the ISS IGAs beyond 2020, it would presumably support an orbital platform for commercial companies. However, a weakness internal to the CCP program may emerge if the ISS IGAs continues to be extended indefinitely and CCP continues to receive federal appropriations. Under those circumstances, commercial companies may become dependent on federal subsidies and lead to cost growth. The TVA and USEC case studies are instructive. They suggest that the longer the federal government insulates the CCP program from market forces, the more it risks creating a subsidy-dependent program. In such a program, the costs increase and the structure becomes institutionalized and less vibrant. As a result, it would become a substantially weakened program. When considering the TVA case study, the early success of this New Deal legislation stands in contrast to recent decades. Since 1959, the TVA has amassed over $25 billion in debt and customer costs have increased as compared to rival utility customers. TVA is often criticized for mismanagement and poor oversight. Another example is the USEC. While USEC has been a major beneficiary of various U.S. government nuclear subsidies throughout the 1990s to present day, the company went bankrupt due in part to its strong dependence of these subsidies. Today, an indefinite extension of ISS may distort market forces in commercial spaceflight by not enabling commercial companies to develop a sustainable a market.

Whereas a roadmap may enable NASA to set an ambitious course for commercial companies, if Congress underfunds or inconsistently funds CCP, a problem arises. The roadmap cannot work if it does not have sufficient funds to replace funding gaps. A roadmap should be a guiding mechanism, not a replacement for congressional appropriations or milestone accomplishments. Similarly, the estimates built into a roadmap should be carefully considered based on credible data and should avoid being overly optimistic. Overly optimistic estimation was one of the main issues that arose during development of the U.S. Supersonic Transport program. In this program, internal FAA estimates on supersonic commercial airliners did not map to economic realities of the airline industry. A large number of aircraft and flights were anticipated and never came to fruition, as demonstrated by the economic failure of the Concorde.

Opportunities

In February 2015, Russia announcement that it is considering an ISS extension to 2024; thereafter, it may undock Russian ISS elements and build a new Russian space station. In the Argument section of this paper, the authors describe potential consequences of Russia's announced undocking from ISS in 2024. However, recent economic trends in Russia and budget cuts to Roskosmos also play a role.

The Russian economy is experiencing a downturn from the low price of crude oil and sanctions imposed by western countries in response to the crisis in Crimea. In April 2015, Russia announced that it would cut Roskosmos "by 35% or 2 trillion rubles ($37 billion) over the next decade."[29] Igor Komarov, Head of Roskosmos, elaborated on these cuts: "The cost of the program's projects has undergone significant changes over the last year given the prevailing economic conditions, changes in exchange rates and changes in the level of inflation."[30]

These cuts to Roskosmos do not guarantee that Russia will cancel its stated goal of building a new space station by 2023; however, the cuts call into question whether Russia can achieve this goal.[31] Therein lies the opportunity for ISS partners. If at any point before 2024, Russia decides to cancel plans to develop its own orbital facility that uses Russian ISS elements, then Russia may choose to extend its partnership in ISS, leaving all essential ISS elements intact.

There does not currently exist a roadmap for commercialization of LEO nor a central organization responsible for this activity, per discussion with the NASA CCP Office. Such a roadmap would provide commercial companies and potential partners with an idea of NASA's near- and long-term goals for the CCP program and commercialization of LEO, and this may attract private investment in commercial LEO capabilities. A roadmap also provides an opportunity for interested stakeholders to understand the intentions of the federal government in LEO; this avoids surprises and encourages sustained investment in a stable environment for business.

Threats

There exist a number of potential threats to extension of the ISS IGA beyond 2020, including international politics, congressional appropriations to NASA (described in further detail below), the opportunity cost of pursuing an ISS extension, change(s) in the national space policy and vision during successive presidencies, increased maintenance costs of an aging orbital facility, and the increased risk of catastrophic failure as ISS reaches end-of-life, potentially endangering astronauts and requiring abandonment and/or de-orbiting of ISS

In September 2014, the NASA Office of Inspector General (IG) released a report on NASA's plans to extend ISS operations to 2024. In this report, the IG calls NASA's $3 to $4 billion

[29] (Kottaso, I. 2015)
[30] Ibid.
[31] Ibid.

annual cost estimations for ISS out to 2024 "overly optimistic."[32] In addition, the IG found that NASA does not plan to maintain any contingency funds for ISS operations out to 2024. Moreover, NASA commercial cargo companies have limited capability to deliver large replacement parts critical to ISS operations, such as, solar arrays and radiators should maintenance be required.[33]

Relevance of a roadmap is contingent on focused, sustained investment. In a 2013 article published to The Space Review, Dr. Harley Thronson relates a strategy espoused by Napoleon Bonaparte to NASA's current horizon goal: human spaceflight to Mars. "As one of history's most successful strategists, Napoleon recognized that there are few greater threats to grand enterprises than distraction, the calendar, and diffuse or disparate goals," writes Thronson.[34] He continues by stating that "overcoming these threats requires unwavering focus on the essential elements of success while excusing distracting, albeit alluring, activities."[35] The historical analogy of the Atomic Energy Commission's (AEC's) Power Reactor Demonstration Program (PRDP) is also instructive in this regard. This program was plagued by the lack of a clear, unwavering path. The AEC initiated multiple rounds of proposals for nuclear reactor development in an ad-hoc manner. This approach by PRDP contributed to the lack of initial growth in commercial nuclear reactors in the 1960's.

Whereas the roadmap policy that the authors recommend in this paper does not specify human spaceflight to Mars, the connection is clear. Whether the goal of a roadmap is human spaceflight to Mars or a projection of government demand in LEO, continuity and sustained funding play integral roles in achieving these goals. An area of concern for NASA since the inception of the CCP has been a lack of continuous or adequate federal appropriations (see Table 1).[36,37]

Table 1. Annual budget request and budget authority for CCP

Fiscal Year	President's Budget Request (millions of then-year dollars)	Budget Authority (millions of nominal dollars)
2009	150	50
2010	0	0
2011	500	321
2012	850	397
2013	830	525
2014	821	696
2015	848	805
2016	1,244	TBD

[32] (NASA OIG 2014 iii)
[33] (NASA OIG 11)
[34] (Thronson, H. 2013)
[35] Ibid.
[36] (Clark, S. 2015)
[37] (National Space Society 2014)

As shown in Table 1, a disparity exists between budget requests and budget authorities over the past several fiscal years. This disparity has led to protracted milestones in the CCP, and as NASA Chief Financial Officer, David Radzanowski described during an FY 2016 congressional hearing, future mismatches in funding requests and appropriations may further delay the CCP. Delays due to inadequate funding pose an external threat to the program and the roadmap that the authors propose. As ISS reaches end-of-life and the prospect of ISS partner withdrawal increases, timely investment of CCP is of critical importance in order to help a nascent commercial human spaceflight industry continue to grow and become self-sustaining.

Summary and Assessment

This report identifies key themes and lessons learned from historical analogies of government to commercial function transfers, which are comparable to NASA CCP. Case studies include the United States Airmail, the Tennessee Valley Authority, Atomic Energy Commission's Power Reactor Demonstration Program, the Federal Aviation Administration's Supersonic Transport program, and the United States Enrichment Corporation. These case studies reveal that perceived demand as the strongest driver of success in public-private partnerships. Moreover, the longer the government supports demand within a market, the more likely the market fails to become self-sustaining. However, if government support is withdrawn too soon before new commercial firms mature, private demand may not be sufficient to sustain the market. The authors' two policy proposals provide a path for government demand that is sufficient in duration and scope to sustain private innovation rather than hamper it.

CCP is designed to facilitate the development of a U.S. commercial crew transportation capability. The goal is to achieve safe, reliable, and cost-effective access to and from ISS and LEO. Specifically, the authors study when and under what conditions did some of these government to commercial function transfers occur. The two policies proposed in this paper are: the extension of ISS Intergovernmental Agreements, Implementing Arrangements, and Memorandums of Understanding beyond 2020 and development of a roadmap to help forecast NASA needs for LEO as NASA transitions from a supply- to a demand-side supporter.

To implement these policy solutions, NASA should first start with the extension or creation of a new ISS agreement. The United States has already taken an important first-step by declaring its desire for ISS operations to at least 2024. Furthermore, Canada and Russia have also expressed interest in the station's operation to 2024. Therefore, the United States should focus on obtaining a public commitment from participating ESA countries and Japan. A public commitment today creates the opportunity for formal negotiations on a final agreement between the partner states.

For implementation of the second policy proposal, NASA should vet, debate, and approve a proposed LEO roadmap through NASA's Executive Council and Senior Management Council. This not only ensures compliance with NASA's own internal procedures but also ensures buy-in from senior NASA leadership. However, NASA should not exclude industry input and feedback once the roadmap enters into internal development work.

Certainly, NASA can take steps towards addressing the other LEO workshop recommendations outside of the two proposed policies. However, the five remaining years on the current ISS agreement is a relatively short timeline in the field of space systems. Lessons from past case studies demonstrate that companies are willing to accept significant risks in a new market if companies perceive a potential for profits. The authors believe that the two policies channel private entrepreneurship towards CCP's goal and extend the economic influence of the United States to LEO.

Appendix A-1: Privatization of the United States Airmail

Overview

The case study on the development of the vast commercial airliner network can be found rooted in U.S. interests to promote an American air transportation system. In the early 20th century, leading through the end of World War I, there were many stages of government interest in utilizing aircrafts for non-military purposes. Interest in creating and investing in a robust commercial airline became prominent in the post-World War I years. This ultimately resulted as part of a growing interest in taking advantage of air services that had the potential to be time efficient, while also increasing American prestige amongst the international community. When looking at the historical nature of the development of commercial airliners, it is evident that air-mail was the entry-point to which the government was able to begin creating both a regulatory framework for the adaptation of air transport technology.

The case for commercial airmail and the eventual move from airmail to transporting passengers ultimately became a success story that is evident not only in the regulatory framework in the United States, but the thriving success of today's commercial airliners. Throughout the 1920s and into the early 1930s, major legislation was passed through congress and adopted to ensure that regulatory standards were in place. This complex case study is not only able to provide a background on how public-private partnerships handle different types of service and oversight contracts, but also the creation of a regulatory body for new technological advancements that have not been dealt with before.

Background

The United States Postal Service (USPS) quickly embraced the idea behind utilizing flight for air service. The fast-paced development of airplanes since the beginning of the 20th century took on more than just a means of advancing technological capabilities but also forced regulatory frameworks to adapt to new and emerging systems.

Many scholars have argued that the overlap between federal regulation and U.S. commercial airliners began with the fast-paced growth of air transport and increasing interests in creating safe and cost-efficient standards for pilots that could inevitably lead to the potential for creating a mainstream means for transporting passengers by air. Recently other historians have begun to argue that the American airline industry really began as an entity of the federal government. The airline industry began in the 1920s when there were contracts from USPS to carry out the airmail program of the United States.[38]

The development of airmail can be seen within the larger reaches of a fast and developing government and commercial airliner system, where motivation for increasing air transport to

[38] (Russell, D.L. 2003); (Rose, N.L. 1985)

increase efficiency in travel and speed, with the eventual potential for more cost-effective transit for both cargo and individuals. One of the primary ways this development occurred was through USPS interest in creating a national airmail travel routes that spanned across areas of the United States that either difficult to reach and/or lacking postal service ground facilities. While airmail generally became more popular and prominent in the post-World War I years, there were a few instances of more experimental airmail payloads. The War encouraged the creation of more advanced aircrafts, capable of carrying heavier payloads and better dependability.[39]

Airmail services in the United States began on unstable grounds, when the time period leading up to the end of World War I proved to be a new and unreliable time for government air transport. Before 1918, interest and participation in airmail really began when U.S. Army planes saw airmail as an extra service that could come out of the increased interest in developing airplanes. During WWI, the rise of an experimental air route was authorized by Congress for $100,000 to provide airmail services between New York and Washington, DC.[40] Little success from this air route occurred due to many reasons, but primary concerns were divided between pilot safety and economic profit. These two reasons may seem different, but both were due to a lack of any formal structure to regulate an emerging airline sector. In addition to these two domestic factors, the United States was heavily concerned about international rise in developing commercial airline routes.

The risks airplane pilots took during the early ears after WWI was particularly dangerous. Without any pilot safety standards, nor regulatory standards for addressing these concerns, pilots generally had a four-year life span. Flying conditions were not adequate in open cockpit planes that did not have the proper instrumentation, gear, and landing conditions suitable for flight. Over the next three years, especially with an attitude supporting airmail transit through all types of weather conditions, there were 27 pilot fatalities. Beginning in 1919, pilots flying among these experimental routes began to protest about the current administrations neglect of pilot safety standards and conditions.[41]

When the Harding Administration entered in 1921, the United States was already lagging behind in the air transportation regulation. The new administration carried with it a new set of policy priorities regarding pilot safety and conditions. This included, but was not limited to, improved airport facilities with a lighted-up system that allowed for night time flying across the country, pilot training standards, upgraded airmail integration and aircrafts, and scheduled inspections for all vehicles used. The result of these regulatory standards was clear when airmail pilot fatalities dramatically decreased after these new practices became standard.[42]

There were a few primary pieces of legislation that formalized as a result. First, the Air Mail Act of 1925, or the Kelly Act, allowed USPS to officially provide commercial airliners with contracts

[39] (Levine, M.E.1975, p. 317); (Lewis, W.D. 2000, p. 9)
[40] (Fraher, A. L. 2014, p. 32)
[41] (Fraher, A. L. 2014, p. 33); (Levine, 319)
[42] (Fraher, A. L. 2014, p. 35)

for national mail routes. By 1927, all contracts were given to commercial airliners. Federal interest in aviation development, especially allowing the industry to thrive, became prominent during the Hoover administration. "Tremendous" effort by the Hoover administration by the time 1930 came around can be seen through two folds: (1) "the de jure regulation over the aircraft industry by the Aeronautics Branch of the Department of Commerce"; and (2) "the de facto regulation of the airline industry by the Post Office."[43]

The relationship surrounding USPS and commercial airliners is both complicated and has been argued by scholars to have many reasons for its success. During the 1920s and especially after government interest in airmail and commercial airliners took-off in 1918, there was a clear debate to how the public-private partnership should exist. Should the government have a customer-service relationship or an oversight/regulatory relationship? This point of contention became the primary debates as the airline industry continued to develop both in technological capability and in the number of commercial airliners throughout the 1920's. Motivation for the government to support commercial airliners did not originate in economic profit, but instead focused on the development of a thriving American commercial airliner network. Instead of the need to justify public involvement in the private sector, the use of indirect subsidies was able to create an adequate justification economically supporting an industry that was not profitable.[44]

Walter Folger Brown, the postmaster general under the Hoover administration, has been credited with instilling the regulatory frameworks that allowed for larger airline industry members to thrive. When airmail service began in the early 1920s, the cost of using airmail service was approximately $17 million, despite its stamp revenue coming out to only about $5 million. The result was the private industry support for over forty-five air carriers who depended primarily on federal airmail contracts.[45]

Throughout the 1920s, the cost slowly became more profitable for the commercial air carriers, while also providing less of an economic burden for USPS. Overall, the ton per mile costs were decreasing and the public began to have more confidence in the airmail program as the rate of successful flights became more obvious and standard. Despite more economic confidence, public opinion was still uncertain throughout the 1920s on both the economic and safety value of flying passengers on airplanes.[46] Much of this changed when the McNary-Watres Act passed in 1930 which stated that "air carriers would be paid for the space set aside in their aircraft for air mail…it also empowered the postmaster general to extend or consolidate air mail routes as he wished, as well as to make route awards only to the lowest responsible bidder who had owned an airline operating on a schedule for at least 250 miles over a 6-month period."[47] The transition from subsidized-based agreement to a per pound contract that was more simplified and created

[43] (Van der Linden, F.R. 2015, p. IX)
[44] (Van der Linden, F.R. 2015, p. VII); (Fraher, A. L. 2014, p. 40); (Heppenheimer,T.A. 1995, p. 32)
[45] (Russell, D.L. 2003, p. 30)
[46] (Levine, M.E.1975, p. 318)
[47] (Russell, D.L. 2003, p. 30)

the basic public-private relationship that would last a long time until commercial operators were able to function independently.

Challenges and Outcomes

The commercialization and development of the American private airline industry met many challenges along the way. The ability to develop, support, and integrate a new regulatory framework for such a fast-growing industry is a challenge in itself, but the three primary issues arose when: (1) new government contracts encouraged large airliners to form; (2) creating government to commercial contracts/bidding system that suited both economic/services incentives for the government, while also developing a larger commercial airline framework; and (3) creating a regulatory system for a new transportation sector.

Despite the large number of private airliners interested in bidding for government contracts, the way in which bids and contracts were given, posed a rather large challenge to smaller companies who were unable to handle the load. Also, there were a limited amount of contracts, providing only a few slots. As a result, many of the small to medium airliners were forced to merge, while larger companies have a significant advantage, with the immediate ability to handle the contracts available. This is visible in the CCP program as well, where the more well-known and popular space companies have been able to successfully gain more leverage and larger percentages of the NASA bids.

Comparisons to NASA CCP

This particular case study focuses not as much on the development of technological capabilities but more on building a regulatory system that could accommodate commercial services and contracts with the government. What many historians have argued and generally supported is the way in which the US government supported commercial airliners not because it was profitable, but because they saw the airmail system as an opportunity to economically support the expansion of US carriers beyond the military program of WWI. While, on the other hand, some scholars have argued that the reason for government regulation and intervention in commercial airliners was because government contracts were not

Other parallels to the NASA CCP program can be made through ***international competition***. One of motivational factors some scholars have argued is international technological prestige. The U.S. government feared that the nation would fall behind in aviation development compared to other nations around the world, particularly in Europe. International competition has been a driving force in many technological developments, but in this particular case, it is not the primary driving factor. Compared to CCP, the primary question that can be asked here is whether commercial support from the government in developing private launch, cargo and crew transport will make the United States a more competitive space faring nation. Especially with the current uncertainty of the International Space Station (ISS) contracts, part of the reasoning to develop an independent commercial system is to slowly wave-off dependency on other space agencies for

services and have the capability to maintain constant services to and from ISS under times of unstable political duress. Also, if other countries back-out of ISS and create their own space stations, the United States can still maintain international prestige. Similar to the airmail case study, US interests in investing in commercial airliners were ultimately successful throughout the 20th century in achieving this goal. Many private airliners were able to accommodate to air travel routes the government created/needed, while they were able to expand not only air-mail coverage but also the eventual trust and reputation of both the government and public. This process eventually expanded to other services such as transporting people.

There were a ***limited amount of government contracts*** available at the time and many of the smaller to medium sized airline companies were forced to merge. Similar circumstances have emerged with NASA CCP. Currently, CCP contracts have been limited and have significantly narrowed in correlation with milestone accomplishments. There are many American commercial space companies in existence, but the only a few have had the opportunity to move forward through the program.

The most important comparison that can be made through this case study is the milestone timeline and the step-by-step process taken under government contracts. Commercial airliners during the 1920s were taking large steps to become safer vehicles for pilots, while also raising the level of reliability. The overview of NASA's commercial crew and cargo program reveals an intricate milestones program. The progressions from carrying cargo to ISS to the current and future investments in commercial crew transport are excellent comparisons to public-private partnerships during airmail development.

Appendix A-2: Atomic Energy Commission Power Reactor Demonstration Program

Overview

From 1955 to 1963, the Atomic Energy Commission (AEC) facilitated the Power Reactor Demonstration Program (PRDP). The program was established to generate research and development (R&D) information on various nuclear reactor designs and involve commercial firms in the construction and operation of nuclear power plants. The AEC funded three rounds of proposals during this program but only a small number of plants were successfully completed and operated. AEC's assistance to participating commercial companies included waivers on fuel use charges for the initial years of reactor operations and subsidized R&D contracts. From early 1954 through late 1962, the AEC estimated it had spent $1.275 billion and that industry had invested $500 million in civilian reactor development.[48] Combined, this amount totals over $13 billion in FY15 dollars. Despite this high level of funding, many scholars argue that this program failed to produce more than a few successful reactors because the program confused R&D objectives with demonstration of commercial feasibility of nuclear reactors.

Background

In its infancy, nuclear power was an endeavor by the United States government to harness the tremendous power demonstrated by nuclear weapons in World War II for civilian purposes. However, this effort was secondary to the government's effort on the military applications of nuclear science and technology. The Atomic Energy Act of 1946 created the Atomic Energy Commission (AEC) to oversee the United States entire nuclear portfolio. The AEC's responsibilities included research and development in both military and civilian applications, procurement and protection of fissionable materials, and the security of classified material with nuclear applications. The Act specifically prohibited industry ownership of nuclear power due to security concerns. However, the AEC choose to maintain the contractor system established during the Manhattan Project out of practicality and urgency to continue military development. AEC first developed experimental breeder reactors in 1947. Then in January 1951, the AEC started the Industrial Participation Program where industry technical personnel were granted security clearances to survey AEC reactor data to develop feasibility reports on possible reactor concepts to the AEC.[49] However, despite growing industry involvement, progress on civilian nuclear power remained slow.

In 1954, at the encouragement of the Eisenhower Administration, the Congress passed a revised Atomic Energy Act, which amended the 1946 law to encourage private industry development of nuclear power. This meant that the AEC had acquired a mandate to both regulate and encourage the growth of commercial industry in addition to its original responsibilities. However, industry

[48] (Assessment of the nuclear power industry – final report 2013)
[49] (Mazuzan, G. T., & Walker, S. J. 1984)

showed little interest in developing and investing in nuclear power. The technology uncertainties and high upfront costs remained unattractive to most power companies, so the AEC launched the Power Reactor Demonstration Program (PRDP) in 1955. The first round saw four industry proposals. The AEC evaluated each off of five main criteria:

1. Probable contribution of the project towards achieving competitive nuclear power
2. Cost to the AEC
3. Financial risk to be taken by the proposer
4. Competence and responsibility of the proposer
5. Assurances given against the abandonment of the project

One of the four proposals, from the Nuclear Power Group, was later withdrawn as the companies involved decided to forgo AEC aid and privately developed what later became the Dresden I nuclear plant, a successful boiling-light-water reactor. Liability protection did not exist at the time of the PRDP so companies assumed complete liability.[50] It should also be noted that the AEC received large-scale prototype proposals, which excluded smaller industry participates that could not raise the needed capital for a large-scale project.

In response to this criticism of excluding small-scale projects, the AEC announced a second round of the PRDP. This time the AEC offered to finance and retain ownership of the reactor portion of a developed plant as long as the plant did not produce more than a 40 MW output. This lowered some of the boundaries to entry for smaller companies and avoided any direct subsidy of reactor construction, which was prohibited by the 1954 law. While seven new proposals were submitted for this new round, the AEC only found four acceptable of which only two entered agreements. However, these two agreements were only reached after more than a year of delays due to continued reluctance of the companies to accept financial risk. These delays frustrated Congress, which felt that the United States was beginning to be surpassed by other nations in civilian nuclear power development.

In response to Congressional pressure, a third round was announced in early 1957 under terms similar to round one. This round received several proposals with a variety of new reactor designs. The AEC issued construction permits for these proposals in the late 1950's through early 1960's. Many of these reactors designs would fail as both industry and the AEC were essentially prototyping numerous reactor designs through the PRDP. Later, the AEC announced a modified PRDP third round in 1962, which more explicitly called for large reactors that would demonstrate reliable sources of power rather than prototype new reactor designs.[51] By this time, the AEC had started to see the results of the first and second rounds.

[50] (Assessment of the nuclear power industry – final report 2013)
[51] (Mazuzan, G. T., & Walker, S. J. 1984)

Challenges

During the PRDP, the AEC was also at work developing regulations on nuclear materials and operator licenses as directed by the 1954 act. This responsibility of both regulating and developing an infant atomic industry did lead to controversy and contention. One of the reactor designs submitted in round one of the PRDP in 1955 was highly sophisticated and unproven. The AEC had plans to develop a similar type of reactor, the Experimental Breeder Reactor-II (EBR-II), to serve as a prototype for this design. However, the EBR-II's construction was not expected to be completed until 1959, which was much too late for the proposer company's planned schedule. An AEC safety committee recommended against the concept until further study with the EBR-II, which harks back to problems of mixing R&D with full scale commercial demonstration. However, both the AEC and the proposer company announced that construction would begin on this design in 1956 despite the safety committee's recommendation. This set off a controversy as Congress criticized the AEC for both going against this safety panel's recommendation and for the continual slow growth industry and lack of R&D efforts by AEC.[52] This concern over slow development and potential public safety concerns, led some in Congress to call for a government run demonstration program without industry participation, especially among proponents of public power in general.[53]

Outcomes

Nuclear reactor development during PRDP is shown Figure 2. Of the three round one participants of the PRDP, only Yankee is considered successful. Yankee used proven light water reactor technology, which ultimately became the dominant reactor type in the nuclear market.[54] The other two, Hallam and Enrico Fermi, tried to employ immature technologies and were mostly unsuccessful. The AEC failed to realize the problems of not separating R&D and technology demonstration at a project level when rounds two and three were announced shortly after the PRDP was launched.[55] Again the reactors from the next two PRDP rounds were ultimately unsuccessful because unproven reactor designs were employed. Only in the modified third announced more than six years after the start of the first round, did the AEC finally abandon a policy of multiple reactor design approaches and focus on water reactor designs like one employed at Yankee instead.[56] This final round led to the successful development and operation of Connecticut Yankee, the final plant developed under the PRDP.

[52] (Mazuzan, G. T., & Walker, S. J. 1984)
[53] (Mazuzan, G. T., & Walker, S. J. 1984)
[54] (Allen, W. 1977)
[55] (Allen, W. 1977)
[56] (Allen, W. 1977)

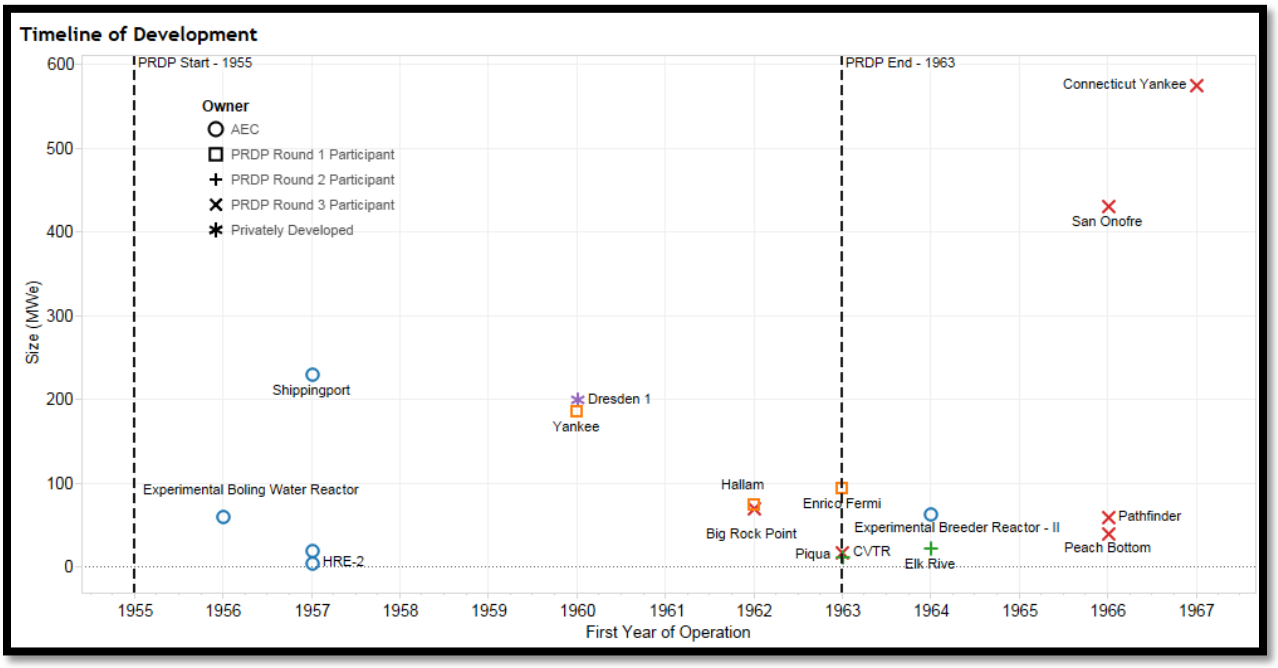

Figure 2: Timeline of Nuclear Reactor Development during PRDP

In short, the PRDP mixed R&D with full scale commercial demonstrations, which are two distinctly different objectives. Had more time been allowed to develop reactors like the EBR-II, the AEC could have informed industry of more proven designs. Instead, while industry provided numerous innovative reactor design ideas, these ultimately only added R&D value rather demonstrate commercial viability. Some also suggest that the AEC only focused on the technical challenges related to nuclear power and was incapable of understanding the financial and other non-technical constraints faced by industry.[57]

Comparisons to NASA CCP

Fundamentally, the biggest difference between NASA's approach to CCP and AEC's approach to PRDP is that CCP is transferring the well understood functionality of low-Earth orbit human spaceflight from NASA to private industry, while the AEC attempted to transfer underdeveloped nuclear reactor technology to private industry. The AEC through pressure from Congress and industry initiated multiple rounds of commercial reactor development, while the AEC itself was still conducting basic nuclear reactor R&D. CCP clearly separated R&D from commercial development with its series of Commercial Development Rounds (CCDevs) in 2010 through 2012 before awarding contracts for development through the Commercial Crew Transportation Capability (CCtCap) contract in late 2014.[58] This allowed for a NASA facilitated learning period

[57] (Allen, W. 1977)
[58] (Siceloff, Steven 2014)

for industry before contracts for full scale commercial development began. Additionally, NASA had lessons learned from its Commercial Cargo Program, which is fully underway and has had two companies successfully deliver cargo to ISS.

However, the AEC PRDP also demonstrates the importance of perceived market demand. Very early on companies saw the possibility of nuclear power as a major new energy source, which is why companies still participated in the PRDP despite the fact that companies assumed full liability. While the market did not lead to a nuclear energy revolution like many had hoped, nuclear power did successfully become a reliable and viable source to satisfy a quantifiable and stable demand for energy within the United States. Today, the market for human spaceflight beyond LEO still lacks any major clarity beyond the needs of ISS. While CCP may successfully facilitate the development of commercial crew rated launch vehicles and spacecraft, the long-term viability of these companies depends on additional market demand for human transportation in LEO that is significant and stable enough for companies to make a profit.

Appendix A-3: Tennessee Valley Authority

Overview

In 1933, the U.S. Congress enacted legislation as part of President Franklin D. Roosevelt's New Deal program, creating the Tennessee Valley Authority (TVA). TVA was designed to include flood control, navigation improvements, reforestation of the lands in the Tennessee Valley, agricultural and industrial development—hydroelectric power by the late 1930s, and the operation of defense plants.[59] The program was created as a federal corporation. In addition to addressing the aforementioned goals, the program had the long-term goal of the program of providing electricity to a large service area and keeping electricity rates low. Operations, infrastructure development, energy production, and delivery of services has been federally funded since its inception. The sale of electricity to customers has comprised the TVA's private part of the public-private relationship.

Criticism of the program has included arguments that TVA has ineffective oversight and that the program has excessive costs, creating liability for the U.S. taxpayer.[60] Moreover, there has been discussion in recent years about the federal government selling the TVA as the 80-year-old program has achieved its original purpose and its sale would potentially enable TVA to reduce taxpayer liability and make long sought infrastructure upgrades.[61]

Background

In order to understand the impetus behind the creation of the TVA, it is necessary to understand the economic conditions of the Tennessee Valley at the height of the Great Depression. Roosevelt identified economic conditions in the South as the most significant economic problem facing the United States. People throughout the Tennessee Valley lived in destitute communities that resembled the mid-nineteenth century United States.[62] Compounding and contributing to widespread poverty were frequent occurrences of droughts and major floods, leading to loss of life, property damage, and soil erosion. Chattanooga, Tennessee, an important manufacturing and railroad hub in the region experienced massive flooding. This was a "serious economic problem and a serious safety issue," says Dr. Daryl Black, Chattanooga History Center Executive Director.[63]

Seventeen years before Congress signed the TVA into law, the United States acquired land in Muscle Shoals, Alabama and constructed a dam. The federal government intended to use electricity produced by this dam to create explosives for World War I; however, "the war ended before the facilities could be used."[64] In successive years, there were attempts to privatize the

[59] (Launius, R. D. 2014)
[60] (Glozer, Ken G 2014)
[61] (Chediak, Mark 2013)
[62] (History of The Tennessee Valley Authority 2013)
[63] (History of The Tennessee Valley Authority 2013)
[64] (The Origins of the Tennessee Valley Authority)

Muscle Shoals site, including a bid from Henry Ford. However, by 1933 several factors played a role in public retention of Muscle Shoals. The United States was plunging further into economic depression as the unemployment rate peaked at 25 percent, and the idea of federal economic intervention was increasingly popular in the United States. Moreover, repeated attempts by Nebraska Senator George W. Harris to retain public control over the site, rejected by previous Republican administrations, was seen by the Roosevelt administration as a viable economic stimulus.[65]

Roosevelt sent a message to Congress on April 10, 1933, supporting creation of the TVA and asking members of Congress to draft legislation for him to sign into law. In the letter, Roosevelt describes the broad potential of this development, beyond that of the Muscle Shoals site:

> It is clear that the Muscle Shoals development is but a small part of the potential public usefulness of the entire Tennessee River. Such use, if envisioned in its entirety, transcends mere power development; it enters the wide fields of flood control, soil erosion, afforestation, elimination from agricultural use of marginal lands, and distribution and diversification of industry.[66]

The president envisioned that the TVA would be a public-private partnership, "clothed with the power of government but possessed of the flexibility and initiative of the private enterprise."[67] Several weeks later, Roosevelt signed the Tennessee Valley Authority Act. The Act whose purpose was to develop a massively depressed region, rich with natural resources, [68] was created:

> To improve the navigability and to provide for the flood control of the Tennessee River; to provide for reforestation and the proper use of marginal lands in the Tennessee Valley; to provide for the agricultural and industrial development of said valley; to provide for the national defense by the creation of a corporation for the operation of Government properties at and near Muscle Shoals in the State of Alabama, and for other purposes.[69]

The program was created as a federal corporation and, in addition to the goals outlined in the Act, the long-term goal of the program has been to maintain a large service area while keeping electricity rates low.[70]

From the onset, the TVA had a major return on investment. Dams were constructed along the length of the Tennessee River, spurring job growth and creating environmental stability that had eluded the region during major floods and droughts in years past. The authority also introduced

[65] (The Origins of the Tennessee Valley Authority)
[66] (Roosevelt, Franklin D. 1933)
[67] (Roosevelt, Franklin D. 1933)
[68] (Beldavs, V., Jeffrey Sommers, & Gregory Anderson 2013)
[69] (Tennessee Valley Authority Act of 1933)
[70] (Launius, R. D. 2014)

electricity, advanced agricultural practices, and modern-day technologies to the people of the Tennessee Valley.[71] During the first 20 years of TVA operations, per capita income in the Valley skyrocketed from 44 to 61 percent.[72] "Imagine being a farmer up in the northern reaches of Hamilton County ... chopping wood and drawing water out of the well. In the course of 8 or 10 years, you have electric lights and electric pumps," Dr. Daryl Black observes.[73] For a region plagued by an endemic cycle of poverty, the TVA brought transformative change.

Challenges

As with many other New Deal programs introduced during the Roosevelt administration, the TVA was politically controversial from the beginning, and was the subject of legislative reform by the Republican Party and litigation by rival utility companies. Whereas by several historical accounts, the TVA was successful in achieving its purpose of providing low cost electricity to Valley residents, among other goals, this success provided a political opening for opponents of the New Deal legislation. Opponents of the TVA felt that the utility was undercutting rivals with low costs and hindering competition. Moreover, the TVA was obtaining funding directly from Congress, and these federal subsidies provided protection to the TVA to which rival utilities did not have access.

By the 1950s, anti-Communist sentiment in the United States was widespread, and New Deal programs were particularly vulnerable to political reform. President Dwight Eisenhower felt that the TVA was inefficient, lacked oversight, and was not subjected to market forces. The president described the TVA as evidence of "creeping socialism" in the United States, and was once quoted as saying, "I'd like to sell the whole thing."[74] During the period from 1950 to 1954, Congress appropriated $1 billion to the TVA, primarily for new infrastructure development, i.e., coal-fired steam plants. However, Republicans cancelled development of several plants; simultaneously, there existed a political impetus to transition TVA to a public-private partnership with other regional utilities, an idea backed by the Eisenhower administration.

While this initiative failed, TVA's Board of Directors was aware of TVA's financial vulnerability in the annual congressional appropriations cycle. In 1959, the TVA and Congress reached a deal that would enable TVA to issue its own bonds with a debt ceiling of $750 million, which the Authority would pay off through TVA revenues: "operating surpluses would be used to pay off the U.S. Treasury's investments in TVA."[75] In addition, as part of the deal, "[t]he TVA agreed to a 'statutory fence' around its service area beyond which it could not sell power."[76] Finally, the TVA agreed to repay $1 billion of appropriated funds from 1933 to 1959 over a period of 54 years at a rate of $20 million per year.

[71] (History of The Tennessee Valley Authority 2013)
[72] (The Great Compromise)
[73] (The Great Compromise)
[74] (The Great Compromise)
[75] (The Great Compromise)
[76] (Glozer, Ken. 2014)

Over the next 20 years, the TVA transitioned from building coal-fired power plants to nuclear power plants, and by the 1980s, the Authority 5 of 17 planned nuclear plants were operational. However, the TVA experienced a number of environmental regulatory hurdles in the 1970s and decreased demand growth. Electricity prices increased for TVA customers during this time as the TVA experienced cost growth as it broadened its portfolio of energy sources. "The 1970s also brought an avalanche of nuclear safety, air and water, and endangered fish and wild-life legislation, which changed everything for electric utilities, but especially for the TVA." (Heritage Foundation 3) The TVA's coal-fired power plants were a major source of pollution in the United States, releasing two million tons of sulfur dioxide into the atmosphere each year by the mid-1970s. The ensuing lawsuit with the Environmental Protection Agency (EPA), which it lost, forced the TVA to retrofit its coal-fired power plants. The Nuclear Regulatory Commission (NRC) also mandated the closure of the TVA's five remaining nuclear power plants. By the 1980s, the Authority was subjected to fines by the NRC and congressional investigations into mismanagement. The TVA was an aging utility company in a time of significant environmental regulatory reform. (Heritage Foundation)

In recent years amid a growing national debt and political will to confront this issue, Republicans and Democrats have revisited the TVA, particularly with regard to the sizable debt of $25 billion that it owes the U.S. Treasury and claims of poor oversight, high costs, and inefficiency. In fact, during the Fiscal Year 2015 budget cycle, President Barack Obama considered selling the TVA and using the estimated $35 billion sale to offset the TVA's debts and direct remaining funds to long sought infrastructure upgrades to TVA facilities. Congressional representatives in the Tennessee Valley fought against the sale of the TVA, and the Authority remained intact. Future legislative action to sell, split up, or privatize the TVA will undoubtedly be pursued in the coming decades unless the TVA addresses and resolves these issues.

Outcomes

Today, the TVA has 17,000 miles of transmission lines and serves 3 million customers over an 80,000-square-mile area. TVA's electrical power system remains the largest in the United States.[77] A number of perspectives exist on the outcomes of the TVA, ranging from adulation for a program that has long-since achieved its goal and revitalized the Tennessee Valley to criticism about a program plagued by inefficiency, ineffective oversight, and billions of dollars in taxpayer liability. The Authority's present situation stands in stark contrast to its nascence, when it was so successful at delivering low cost electricity to a wide area that it attracted the attention of rival utility companies and political opponents of the New Deal.

A review of the historical record shows a mixed legacy for the TVA. The Authority helped to lift the Tennessee Valley out of the Great Depression and delivering what Dr. Daryl Black describes as "unmitigated good" to a destitute, battered region of the United States. However, as electricity

[77] (Launius, R. D. 2014)

costs have increased disproportionately as compared to private utilities, taxpayer liability has soared to billions of dollars, and as infrastructure ages, the Authority looks haggard, sprawling, and in need of reinvention.

Comparisons to NASA CCP

The TVA and CCP share a common goal of economic growth through federal investment. Whereas the TVA revitalized the Tennessee Valley and brought economic and environmental stability to a resource-rich area of the United States, the goal of CCP is to stimulate an emerging space market through commercial cargo and crew flights to the International Space Station with the long-term goal of a stable, widespread commercial market in low Earth orbit. The goals are similar albeit geographically diverse, and the success of the TVA in providing low cost electricity to a wide area during the first several decades of its existence serve as a useful analog for NASA. However, in recent years, the average price of power has disproportionately increased for TVA customers as compared to other regional and national utility companies. Moreover, TVA has incurred billions in debt and has been a frequent target for deficit reduction in Congress. The TVA's early success followed by significant challenges in recent decades serves as a caution for NASA in its implementation of the CCP program. The goal of CCP should be to transfer a historically federal functionality to a commercial functionality. The longer the federal government insulates the CCP program from market forces, the more it risks creating a subsidy-dependent program whose costs increase and whose structure becomes institutionalized and less vibrant.

Appendix A-4: Federal Aviation Administration Supersonic Transport Program

Overview

In 1963, President Kennedy announced the supersonic transport (SST) program to develop a commercial supersonic aircraft. This move was in response to French and British supersonic efforts, which later culminated in the creation of the Concorde. This program was managed by the Federal Aviation Administration (FAA), which specified the aircraft requirements. FAA only awarded funds to Boeing, whose large and complex design resulted in delays and budget overruns. These technical setbacks coupled with civilian concerns over sonic boom noise and environmental concerns, led Congress to cancel SST in 1971 after $700 million in federal funds had been sunk into the program. However, a strong market for supersonic aircraft never developed into the size and scope predicted by the FAA as demonstrated by the lack economic success of the Concorde and the Russian Tu-144.

Background

In the early 1960's, the United Kingdom and France began development on a supersonic aircraft that would later become the Concorde, a commercial carrier that could reach speeds up to Mach 2.[78] These efforts caught the attention of President Kennedy in 1963 after Pam American World Airlines, a U.S. airliner, announced that it would commit to purchase six Concordes. President Kennedy responded with a call for the formation of the U.S. SuperSonic Transport program (SST). President Kennedy felt that the U.S. should not only develop this technology but be the world leader in supersonic flight. He specifically called for the U.S. developed aircraft to be faster and bigger than the Concorde. These specific requirements would ultimately doom the SST program.

The FAA was charged with the supervision of this program. President Kennedy told Congress that the development costs would amount to $1 billion and that industry would cover 25% of the cost. However, aircraft manufactures called for a cost sharing agreement with a federal cost share of 90% due to their unwillingness to invest in the initiative.[79] Only two aircraft makers, Lockheed and Boeing, submitted proposals for the program's sole contract. The FAA selected Boeing's 2707-100 over Lockheed's design despite Boeing's lack of experience in supersonic aircraft. The Boeing 2707-100 design had a swing wing concept, a cruising speed of Mach 2.7, and a passenger capacity of 300. In comparison, the Concorde was fixed wing aircraft with a cruising speed of Mach 2 and a passenger capacity of 100.[80]

[78] (Seebass, Richard 1998)
[79] (Rose, N. L. 1986)
[80] (Celebrating Concorde)

Challenges

Boeing immediately ran into engineering challenges during development. Weight soon became a major issue that forced engineers to abandon the swing wing design. Additionally, the speed requirements began to create issues as well. At Mach 3, heat problems begin to challenge an aircraft's structure, a lesson that Boeing learned only through development due to its lack of supersonic experience.

Furthermore, the SST program proved too far beyond FAA's expertise to manage. While the FAA is responsible aircraft safety certifications, the SST program was the first time that the agency had attempted to design specifications for a new commercial aircraft.[81] FAA was ill prepared to handle the engineering decisions around performance, cost, weight, and capacity factors that are associated with commercial aircraft development.

Controversy also arose around FAA's cost and demand estimates for the SST. A 1963 research study contracted to Booz Allen Hamilton by FAA concluded that the cost for one SST aircraft would be $60 million.[82] However, FAA choose instead to use a cost estimate of $23 million per aircraft based on an engineering analysis produced by an inter-agency evaluation group.[83] The FAA also used its own statistical analysis to defend this decision. The lower cost estimate in turn led the FAA to higher estimates of demand for SST aircraft. Initial FAA demand models had in the early 1960's estimated SST demand to be 75 aircraft by the year 1990.[84] However, by 1970 the FAA had adjusted its model to predict an estimated demand for SST aircraft to be around 500-800 by the year 1990.[85] There was some promise of optimism as 26 airlines had the Boeing 2707 on order during its development, which promised demand for 200 aircraft.[86] However, by 1990, only 14 SST aircraft, all Concordes, actually entered in service for passenger flights.[87]

What actually drove Congress to cancel the program in 1971 was concern on the environmental impact of sonic booms and aircraft exhaust in the stratosphere.[88] Committees and study groups sponsored by the FAA often concluded that these issues should not be cause for concern. However, scholars argue that these groups failed to bring in the best experts and instead relied on scientists unfamiliar with the stratosphere. Once experts in the study of the stratosphere were consulted, they contended that depletion of the ozone layer due SST exhausts could occur and, therefore, would pose a major environmental hazard.

[81] (Rose, N. L. 1986)
[82] (Clark, I. D. 1974)
[83] (Clark, I. D. 1974)
[84] (Clark, I. D. 1974)
[85] (Clark, I. D. 1974)
[86] (Seebass, Richard 1998)
[87] (Haria, Rupa 2013)
[88] (Clark, I. D. 1974)

Outcomes

When the Senate canceled the SST program in 1971, it brought to a close a U.S. attempt to commercialization supersonic flight. While engineering and environmental challenges drove the Senate's decision, the market for passenger supersonic flight would have made the program a failure regardless. Even had the Boeing 2707 entered been successfully developed and entered into service, it's likely that its associated costs for upkeep and fueling would have made it a market failure. This is argument is certainly supported by the outcome of the Concorde, which was successfully developed and began service in 1976 but was decommissioned in 2003.

While the Concorde drastically cut time on transatlantic flights, ultimately passengers were hard pressed to justify the over $6000 price for one-way tickets.[89] The extravagant cost came from not only fuel costs, which were several times higher than a Boeing 747, but also from the maintenance costs which were approximately seven times higher than that of Boeing 747.[90] This is why U.S. industry balked at contributing heavily towards SST in the 1960's. They understood that the market demand was for cheap and reliable air travel rather than for speed. Additionally, the Soviet Union further crowded the commercial supersonic market with its own Concorde equivalent, the TU-144, which began passenger service in 1977 but was soon relegated to just cargo delivery after a series of technical setbacks.[91]

Comparisons to NASA CCP

FAA SST and NASA CCP differ in a number major ways. The first is that NASA CCP is developing private industry to take over a function that NASA has decades of experience performing itself. The FAA had no experience in supersonic aviation, much less the institutional knowledge to develop the engineering requirements to successfully produce an aircraft. While Boeing struggled with numerous engineering setbacks from a lack of supersonic experience for the development of the Boeing 2707 in the 1960's, the company is well experienced in human spaceflight design and development today. Boeing, SpaceX, and other past CCP participates heavily borrow engineering concepts and designs used during the Apollo and Shuttle programs and utilize the expertise of NASA employees. Second, unlike FAA SST, which selected a single company for a single contract, NASA CCP has had several phases of promoting human rated spacecraft development through its Commercial Crew Development programs with numerous participants beyond the two selected for the current NASA contract to transport astronauts to ISS. This has generated healthy competition among CCP participants and demonstrates industry's interest within this market. However, NASA and CCP participates should take note of the overly optimistic numbers for perceived SST demand that FAA, Boeing, and foreign governments and companies used to justify development of supersonic aircraft. These figures

[89] (Haria, Rupa 2013)
[90] (Seebass, Richard 1998)
[91] (Zarakhovich, Yuri 2000)

simply misread the market for supersonic travel that not even the Concorde could overcome despite decades of successful service.

Appendix A-5: Privatization of the United States Enrichment Corporation

Overview

Congress established the United States Enrichment Corporation (USEC) in 1993 through passage of the Energy Policy Act of 1992.[92] The function of this government corporation was to manage and operate the Department of Energy's (DOE) low-grade enriched uranium processing facilities. USEC was fully privatized in 1998 after its privatization plan won presidential approval in 1997. This function transfer required the government to resolve issues around assets, liabilities, national security concerns, leasing, and commercialization rights for government developed advanced enrichment technology. Despite various DOE subsidies, USEC has struggled as a private company. The company filed for chapter 11 bankruptcy in 2014 from which it has only recently emerged under its new name Centrus Energy Corporation.

Background

The United States government first began to enrich uranium in the 1940's for the purposes of nuclear weapons development.[93] By the 1960's, the government also began to sale some its enriched uranium to commercial industry for the development of privately operated nuclear power plants. By 1970, the United States government's owned and operated enrichment facilities became the primary dominate supplier of low enriched uranium for nuclear power plants worldwide.[94] During this time period, with the United States having a near monopoly on the low grade enrichment market, the Nixon Administration was the first to propose privatization of the government's enrichment business in the early 1970's.[95] However, the United States steadily lost uranium enrichment market share throughout the 1970's and 1980's. Foreign competitors took advantage of the ability to study the pricing and proprietary information of DOE-owned enrichment facilities, which were required by law to provide that information to Congress.[96]

Congress began the process of separating enrichment production from the federal control with the Energy Policy Act of 1992. This Act created the United States Enrichment Corporation (USEC), a government-owned entity that inherited DOE's enrichment assets and activities. The Act exempted USEC from the need to obtain annual appropriations from Congress and comply by federal procurement rules[97]. USEC soon achieved record production levels and lowered production costs as a result of the change. This fueled momentum for USEC to become a private

[92] (Centrus energy corp. – history 2015)
[93] (Centrus energy corp. – history 2015)
[94] (Logsdon, J. M., Williamson, R. A., & Hertzfeld, H. R. 2000)
[95] (Centrus energy corp. - history. 2015)
[96] (Logsdon, J. M., Williamson, R. A., & Hertzfeld, H. R. 2000)
[97] (Orszag, P. R. 1996)

company. In fact, a 1995 Government Accounting Office report estimated a privately owned USEC could achieve 11 percent higher revenue than as a government owned company.[98]

USEC was fully privatized in 1998 after its privatization plan won presidential approval in 1997 and with the passage of the 1997 USEC Privatization Act by Congress.[99] The company issued $3 billion worth of stock to the U.S. Treasury for sell on the open market in 1998. [100]As part of its privatization plan, USEC agreed not to lay-off more than 500 employees at its enrichment facilities within its first two years of operations and to keep the both of its enrichment plants operational until at least 2005.[101] Additionally, USEC was allowed to issue bonds and was granted tax exemption on the two enrichment facilities it leased from DOE. Moreover, USEC was made the exclusive marketing agent for the United States government's enriched uranium services.

Challenges

In response to the collapse of the Soviet Union in the early 1990's, the Clinton Administration struck a deal in 1993 with the new Russian government to safeguard its large stockpiles of nuclear material. Under the deal, the United States would import nuclear material for USEC to purchase. USEC would process down the uranium and then sell the uranium for reactor fuel. While deal made since for national security reasons, the deal forced USEC to buy uranium at a 20 percent higher cost compared to what could be produced domestically in the United States.[102] Thus, USEC response was to initially delay the implementation of the agreement. However, the company ultimately entered a 10-year agreement with Russia to fulfill the United States government's request.

Throughout the process of privatization, USEC and DOE had to decide on the division of existing liabilities and contributions to civil service and federal employee health and retirement plans.[103] Additionally, enrichment technology poses serious non-proliferation risks for national security. USEC had to assure the government that security would not be sacrificed to improve internal efficiency.[104] The United States' government agreed to accept all liabilities that arose from USEC operations between the transition from a government owned to a privately owned corporation. Furthermore, DOE transferred 45,000 metric tons of natural uranium to USEC to allow USEC to fulfil its existing contracts. USEC later argued that up to 20% of the transferred

[98] (Orszag, P. R. 1996)
[99] (Logsdon, J. M., Williamson, R. A., & Hertzfeld, H. R. 2000)
[100] (Logsdon, J. M., Williamson, R. A., & Hertzfeld, H. R. 2000)
[101] (Logsdon, J. M., Williamson, R. A., & Hertzfeld, H. R. 2000)
[102] (Orszag, P. R. 1996)
[103] (Logsdon, J. M., Williamson, R. A., & Hertzfeld, H. R. 2000)
[104] (Orszag, P. R. 1996)

uranium was contaminated for which USEC and DOE had to negotiate a compromise on dividing the decontamination costs.[105]

Outcomes

In 1995, as a government owned company, USEC oversaw 4,350 workers and generated a net income of $448 million.[106] By 2011, the company had reduced its workforce down to 1,800 but still generated a net income loss of $541 million after years of steady decline in net income.[107] In early 2014, the company listed assets of $70 million and debt of $1.07 billion as it filed for Chapter 11 bankruptcy.[108] As shown in Figure 3, USEC's stock lost over 99% of its value from its initial public offering in 1998 to 2014. Investor confidence eroded as unforeseen cost pressures, innovate failures, and lack of nuclear power growth weighed on the company. While the enrichment market is essentially an oligopoly that consistent of a few major market players, USEC and its competitors suffered major financial losses as a global surplus of nuclear fuel. The surplus was the result of the Fukushima reactor meltdowns in Japan and reactor shutdowns in Germany in 2011.[109] The company emerged from bankruptcy in September 2014 under the new name Centrus Energy Corporation.[110]

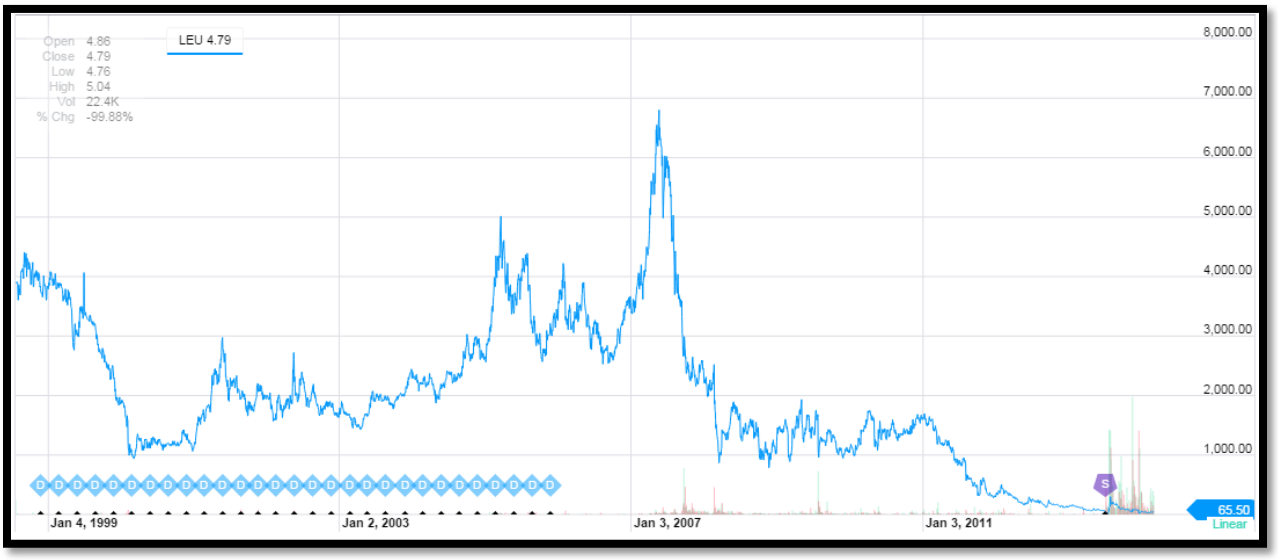

Figure 3: USEC's stock price (symbol - LEU) has lost over 99% of its value since 1998 (Source: Yahoo Finance)

[105] (U.S. enrichment corporation privatization 2006)
[106] (USEC inc. 1999 annual report 1999)
[107] (USEC inc. 2011 annual report 2011)
[108] (McCarty, D., & Milford, P. 2014)
[109] (McCarty, D., & Milford, P. 2014)
[110] (Centrus energy corp. emerges from chapter 11 restructuring 2014)

When then-President of USEC, William Timbers, testified before Congress in 1995, he stated that the privatization of USEC "will mean the elimination of the U.S. Government from the uranium enrichment business."[111] However, that statement is far from the present reality. Today, USEC (Centrus) is still heavily reliant on DOE. Currently, DOE is funding 80 percent or $241 million of the development costs for a new USEC enrichment plant in Ohio.[112] DOE also still owns the plants that USEC leases for enrichment. Moreover, a 2014 Government Accountability Office report expressed legal concerns with DOE's uranium transactions with USEC in 2012 and 2013.[113] These concerns included DOE's acceptance of excessive liability from USEC and transfer of nuclear material to USEC without proper authorization.[114] Additionally, the USEC's recent hiring of DOE's deputy administrator as its new CEO has brought this relationship under further criticism from Congress.[115]

Comparisons to NASA CCP

The privatization of USEC does not share many characteristics with CCP. However, it is an example where the transition of a government function over to private industry is not enough to overcome market headwinds. Despite USEC's flexibility to cut cost and reduce its workforce, the fall in demand for nuclear material from the utilities sector drove USEC into bankruptcy. While the burden of the Russian import deal imposed on USEC by the federal government did not help USEC's profitability, the DOE has provided significant subsidies to USEC both through materials, liability acceptance, infrastructure, and expertise. For CCP, the question of how much companies depend on NASA for similar support remains to be seen. NASA allows companies to lease pads for launch. NASA also regularly provides expertise to CCP participants that assist with engineering development.

[111] (Statement by William Timbers 1995)
[112] (McCarty, D., & Milford, P. 2014)
[113] (Background and excerpts from GAO report 2014)
[114] (Background and excerpts from GAO report 2014)
[115] (Dixon, D. 2015)

Bibliography

Achenbach, J. (2014). NASA: Obama extends international space station operation until at least 2024. *Washington Post*.

Agreement among the Government of Canada, Governments of Member States of the European Space Agency, the Government of Japan, the Government of the Russian Federation, and the Government of the United States of America Concerning Cooperation on the Civil International Space Station, Agreement. (1998).

Allen, W. (1977). *Nuclear reactors for generating electricity: U.S. development from 1946 to 1963* No. R-2116-NSF). Santa Monica: The Rand Corporation.

Assessment of the nuclear power industry – final report (2013). Burlington, MA: Navigant Consulting, Inc.

Background and excerpts from GAO report: Enhanced transparency could clarify costs, market impact, risk, and legal authority to conduct future uranium transactions (2014). Office of Senator Ed Markey.

Beldavs, V., Jeffrey Sommers, & Gregory Anderson. (2013). 8 Apr. 2013. Move over NASA and make room for the TVA of space: A model for accelerated commercial space development. Message posted to http://www.thespacereview.com/article/2274/1

Bowie, M. (2011). *Office of International and Interagency Relations Human Exploration and Operation Division.* Retrieved from http://oiir.hq.nasa.gov/human_exploration.html

Clark, I. D. (1974). Expert advice in the controversy about supersonic transport in the united states. *Minerva, 12*(4), 416.

Clark, S. (2015). NASA presses congress for more commercial crew funding. Retrieved from http://spaceflightnow.com/2015/02/03/nasa-presses-congress-to-pay-for-commercial-crew/

Clark, S. (2015). Russian space agency endorses ISS until 2024. *Spaceflight Now*.

Celebrating concorde. Retrieved February 1, 2015, from http://www.britishairways.com/en-us/information/about-ba/history-and-heritage/celebrating-concorde

Centrus energy corp. - history. (2015). Retrieved April/4, 2015, from http://www.centrusenergy.com/company/history

Centrus energy corp. emerges from chapter 11 restructuring. (2014). Retrieved March/3, 2015, from http://www.centrusenergy.com/news/centrus-energy-corp-emerges-chapter-11-restructuring

Chediak, Mark (2013). *Obama Budget Ponders Sale of Tennessee Valley Authority*. Retrieved from http://www.bloomberg.com/news/articles/2013-04-11/obama-mulls-sale-of-tennessee-valley-authority-in-budget-plan

Commercial crew program (2014). NASA. Retrieved from http://www.nasa.gov/exploration/commercial/crew/index.html

De Selding, P. B. (2015), Canada's new space budget extends ISS commitment to 2024. *Space News*.

Dixon, D. (2015). Ex-energy official's $1.7 million gig draws fire. *Politico.*

Extending the operational life of the international space station until 2024 (2014). (Audit Report No. IG-14-031) NASA Office of Inspector General.

Fact sheet: 2013 national space transportation policy (2013). The White House.

Fraher, A.L. (2014). *The Next Crash: How Short-term Profit Seeking Trumps Airline Safety*. Ithaca, NY: Cornell University Press.

Gerstenmaier, W., Scimemi, S., Stofan, E., McAlister, P., Nield, G., Johnson, G., et al. (2014). ISS LEO commercialization. *NASA Commercial LEO Workshop*, Washington, DC.

Glozer, Ken G (2014). *Time for the Sun to Set on the Tennessee Valley Authority*. Retrieved from http://www.heritage.org/research/reports/2014/05/time-for-the-sun-to-set-on-the-tennessee-valley-authority

Hall, L. (2013). *Space technology mission directorate.* Retrieved March 25, 2015, from http://www.nasa.gov/directorates/spacetech/about_us/index.html

Haria, R. (2013). 2003: Concorde, end of an era. *Aviation Week.*

Harwood, William (2015). Boeing, SpaceX on track for commercial crew flights to station in 2017. *Spaceflight Now*.

Heppenheimer, T. A. (1995). *Sloan Technology: Turbulent Skies: The History of Commercial Aviation*. New York, NY: John Wiley & Sons.

Kottaso, I. (2015), Economic crisis hits at heart of Russia's pride: Its space program. *CNN*.

Launius, R. D. (2014). The railroads and the space program revisited: Historical analogues and the stimulation of commercial space operations. *Astropolitics: The International Journal of Space Politics and Policy, 12*(2-3), 167-179.

Levine, M. E. (1975). Regulating Airmail Transportation. *Journal of Law and Economics*, *18*(2), 317-359.

Lewis, W.D. (2000). *Airline Executives and Federal Regulation: Case Studies in American Enterprise from the Airmail era to the Dawn of the Jet Age*. Columbus, OH: The Ohio State University.

Logsdon, J. M., Williamson, R. A., & Hertzfeld, H. R. (2000). *Privatizing the space shuttle issues and approaches*. Washington, DC: Space Policy Institute.

Mansfield, C. L. (2015). *STS-135: The final voyage.* 2015. Retrieved from https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts135/launch/sts-135_mission-overview.html

Mazuzan, G. T., & Walker, S. J. (1984). *Controlling the atom : The beginnings of nuclear regulation, 1946-1962* University of California Press.

McAlister, P. (2014). Commercial Spaceflight Development Update. Unpublished manuscript.

McCarty, D., & Milford, P. (2014). Uranium producer USEC files for bankruptcy protection. *Bloomberg.*

NASA Strategic Plan 2014 (2014). NASA. Retrieved from https://www.nasa.gov/sites/default/files/files/FY2014_NASA_SP_508c.pdf

Leone, D. (2015), NASA Making Plans for Russia's Secession From ISS. *Space News*.

Oberg, J. (2015), What Happens if Russia Abandons the International Space Station? *IEEE Spectrum*.

Orszag, P. R. (1996). *Privatization of the U.S. enrichment corporation: An economic analysis*

Pappalardo, J. (2007), How does the International Space Station dodge space junk? *Air & Space Magazine*.

Position paper: The NASA commercial crew program (2014). National Space Society.

Roosevelt, Franklin D. Message to Congress Suggesting the Tennessee Valley Authority. 10 April 1933. Retrieved from http://docs.fdrlibrary.marist.edu/odtvacon.html

Rose, N. L. (1986). The government's role in the commercialization of new technologies: Lessons for space policy. *RFF Proceedings*, pp. 97.

Russell, D.L. (2003). *Eastern Air Lines: 1926-1991*. Jefferson, NC: McFarland.

Seebass, R. (1998). History and economics of, and prospects for, commercial supersonic transport. *Fluid Dynamics Research on Supersonic Aircraft*, Rhode-Saint-Genese, Belgium.

Siceloff, S. (2014). *Commercial crew program - the essentials.* Retrieved January 04, 2015, from http://www.nasa.gov/content/commercial-crew-program-the-essentials

SpaceNews Editor. (2015), Good news from Russia on ISS. *Space News*.

Statement of William H. Gerstenmaier associate administrator for human exploration and operations national aeronautics and space administration: Subcommittee on Space Committee on Science, Space and Technology, U.S. House of Representatives, First Session (2015).

Svitak, A. (2015), Russia to quit ISS in 2024, build space base in LEO. *Aviation Week*.

Tennessee Valley Authority Act of 1933. 18 May 1933. Retrieved from http://www.ourdocuments.gov/document_data/pdf/doc_065.pdf

The Great Compromise. *Tennessee Valley Authority*. Retrieved from http://www.tva.gov/heritage/great_compromise/index.htm

The Origins of the Tennessee Valley Authority. *The New Deal Network*. Retrieved from http://newdeal.feri.org/tva/tva01.htm

Thronson, H. (2013). If you set out to go to mars, go to mars! Message posted to http://www.thespacereview.com/article/2345/1

Turnbough, L. (2012). *Commercial crew & cargo.* Retrieved in 2015, from http://www.nasa.gov/offices/c3po/about/c3po.html

USEC inc. 1999 annual report (1999). USEC Inc.

USEC inc. 2011 annual report (2011). USEC Inc.

Van der Linden, F. R. (2015). *Airlines and Air Mail: The Post Office and the Birth of the Commercial Aviation Industry*. Louisville, KY: University Press of Kentucky.

Wiles, J. (2015). *About human exploration and operations.* Retrieved March 25, 2015, from http://www.nasa.gov/directorates/heo/home/about.html

Zarakhovich, Y. (2000). The concordski. *Time.*

Works Consulted

Abeyratne, R. (2013). Commercial space travel: Security and other implications. *Journal of Transportation Security, 6*(3), 257-270. doi: http://dx.doi.org.proxygw.wrlc.org/10.1007/s12198-013-0115-1

Allen, W. (1977). *Nuclear reactors for generating electricity: U.S. development from 1946 to 1963* No. R-2116-NSF). Santa Monica: The Rand Corporation.

Assessment of the nuclear power industry – final report (2013). Burlington, MA: Navigant Consulting, Inc.

Background and excerpts from GAO report: Enhanced transparency could clarify costs, market impact, risk, and legal authority to conduct future uranium transactions (2014). Office of Senator Ed Markey.

Baltimore and ohio railroad (1827). *The North American Review*, *25*(1), 62.

Basic plan on space policy (2013). Space Policy. Cabinet Office, Government of Japan: Strategic Headquarters for Space Policy, Government of Japan.

Beldavs, V., Jeffrey Sommers, & Gregory Anderson. (2013). 8 Apr. 2013. Move over NASA and make room for the TVA of space: A model for accelerated commercial space development. Message posted to http://www.thespacereview.com/article/2274/1

Bowie, M. (2011). *Office of International and Interagency Relations Human Exploration and Operation Division.* Retrieved from http://oiir.hq.nasa.gov/human_exploration.html

Caves, D. W., & Christensen, L. R. (1980). The relative efficiency of public and private firms in a competitive environment: The case of canadian railroads. *Journal of Political Economy, 88*(5), 958.

CCP independent review. Unpublished manuscript.

Celebrating concorde. Retrieved February 1, 2015, from http://www.britishairways.com/en-us/information/about-ba/history-and-heritage/celebrating-concorde

Centrus energy corp. - history. (2015). Retrieved April/4, 2015, from http://www.centrusenergy.com/company/history

Centrus energy corp. emerges from chapter 11 restructuring. (2014). Retrieved March/3, 2015, from http://www.centrusenergy.com/news/centrus-energy-corp-emerges-chapter-11-restructuring

Chediak, Mark (2013). *Obama Budget Ponders Sale of Tennessee Valley Authority*. Retrieved from http://www.bloomberg.com/news/articles/2013-04-11/obama-mulls-sale-of-tennessee-valley-authority-in-budget-plan

Clark, I. D. (1974). Expert advice in the controversy about supersonic transport in the united states. *Minerva, 12*(4), 416.

Commercial crew program (2014). NASA. Retrieved from http://www.nasa.gov/exploration/commercial/crew/index.html

Commercial market assessment for crew and cargo systems pursuant to section 403 of the NASA authorization act of 2010 (P.L. 111-267) (2011). NASA.

Cullinane, K., & Song, D. (2002). Port privatization policy and practice. *Transport Reviews, 22*(1), 55-75. doi:10.1080/01441640110042138

Cullinane, K., & Song, D. (2002). Port privatization policy and practice. *Transport Reviews, 22*(1), 55-75. doi:10.1080/01441640110042138

Davies, R. E. (1998). *Airlines of the United States since 1914*. New York, NY: Pavillion Books.

Dixon, D. (2015). Ex-energy official's $1.7 million gig draws fire. *Politico.*

Dresden generating station. Retrieved February/12, 2015, from http://www.exeloncorp.com/PowerPlants/dresden/Pages/profile.aspx

Dubbs, C., & Paat-Dahlstrom, E. (2011). *Realizing tomorrow : The path to private spaceflight*. Lincoln: University of Nebraska Press.

Dyer, J. W. (2015). *Aerospace safety advisory panel: Annual report for 2014* No. NP-2015-01-1305-HQ) NASA.

Evans, A. W. (2010). Rail safety and rail privatisation in japan. *Accident Analysis & Prevention, 42*(4), 1296-1301. doi:http://dx.doi.org.proxygw.wrlc.org/10.1016/j.aap.2010.02.007

Extending the operational life of the international space station until 2024 (2014). (Audit Report No. IG-14-031) NASA Office of Inspector General.

Fact sheet: 2013 national space transportation policy (2013). The White House.

Fraher, A.L. (2014). *The Next Crash: How Short-term Profit Seeking Trumps Airline Safety*. Ithaca, NY: Cornell University Press.

Freeman, J., & Minow, M. (2009). *Government by contract : Outsourcing and american democracy* Harvard University Press.

FY 2016 president's budget request summary (2015). NASA.

Statement of William H. Gerstenmaier associate administrator for human exploration and operations national aeronautics and space administration: Subcommittee on Space Committee on Science, Space and Technology, U.S. House of Representatives, First Session (2015).

Gerstenmaier, W., Scimemi, S., Stofan, E., McAlister, P., Nield, G., Johnson, G., et al. (2014). ISS LEO commercialization. *NASA Commercial LEO Workshop,* Washington, DC.

Gholz, E. (2011). Eisenhower versus the spin-off story: Did the rise of the military-industrial complex hurt or help america's commercial aircraft industry? *Enterprise & Society*, *12*(1), 60.

Glozer, Ken G (2014). *Time for the Sun to Set on the Tennessee Valley Authority*. Retrieved from http://www.heritage.org/research/reports/2014/05/time-for-the-sun-to-set-on-the-tennessee-valley-authority

Hall, L. (2013). *Space technology mission directorate.* Retrieved March 25, 2015, from http://www.nasa.gov/directorates/spacetech/about_us/index.html

Haria, R. (2013). 2003: Concorde, end of an era. *Aviation Week.*

Harwood, William (2015). Boeing, SpaceX on track for commercial crew flights to station in 2017. *Spaceflight Now*.

Heppenheimer, T. A. (1995). *Sloan Technology: Turbulent Skies: The History of Commercial Aviation*.New York, NY: John Wiley & Sons.

History of The Tennessee Valley Authority (2013). C-SPAN. Retrieved from http://www.c-span.org/video/?317111-1/history-tennessee-valley-authority

Hossain, M., & Malbon, J. (1998). *Who benefits from privatisation?* Routledge.

Inherently governmental –What is the proper role of government? Readiness Subcommittee of the Committee on Armed Services House of Representatives, House of Representatives, (2008).

Lark, E. (2010). *Economic incentives and tax credits for space resource development: Analogies and ideas*. Ottawa: Space Studies Institute.

Launius, R. D. (2014). *HISTORICAL ANALOGS FOR THE STIMULATION OF SPACE COMMERCE: Monographs in aerospace history, no. 54*. NASA History Program Office.

Launius, R. D. (2014). The railroads and the space program revisited: Historical analogues and the stimulation of commercial space operations. *Astropolitics: The International Journal of Space Politics and Policy, 12*(2-3), 167-179.

Law, J., Mathers, C. H., Fondy, S. R. E., Vanderploeg, J. M., & Kerstman, E. L. (2013). NASA's human system risk management approach and its applicability to commercial spaceflight by jennifer law, charles H. mathers, susan R.E. fondy, james M. vanderploeg, and Eric L. kerstman. *Aviation, Space, and Environmental Medicine, 84*(1), 68.

Leung, R., Sarkani, S., & Mazzuchi, T. (2013). Mission success regulations, their effect on ELV launch success and the applicability to regulating commercial human spaceflight. *Space Policy, 29*(4), 258.

Levine, M. E. (1975). Regulating airmail transportation. *Journal of Law and Economics, 18*(2), 317-359. Retrieved from http://www.jstor.org.proxygw.wrlc.org/stable/725298

Lewis, W.D. (2000). *Airline Executives and Federal Regulation: Case Studies in American Enterprise from the Airmail era to the Dawn of the Jet Age*. Columbus, OH: The Ohio State University.

Logsdon, J. M., Williamson, R. A., & Hertzfeld, H. R. (2000). *Privatizing the space shuttle issues and approaches*. Washington, DC: Space Policy Institute.

MacDonald, A., & Riley, A. (2014). *Public-private partnerships for space capability development: Driving economic growth and NASA's mission*. National Aeronautics and Space Administration: The Tauri Group.

Mansfield, C. L. (2015). *STS-135: The final voyage*. 2015. Retrieved from https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts135/launch/sts-135_mission-overview.html

Mazlish, Bruce,,. (1965). *The railroad and the space program : An exploration in historical analogy*. Cambridge, Massachusetts [etc.]: MIT Press. Retrieved from /z-wcorg/

Mazuzan, G. T., & Walker, S. J. (1984). *Controlling the atom : The beginnings of nuclear regulation, 1946-1962* University of California Press.

McAlister, P. (2013). *The cost, schedule, risk,trade.* Unpublished manuscript.

McAlister, P. (2014). *The commercial crew program: What is it and why are we doing it?* Unpublished manuscript.

McAlister, P. (2015). *NASA administrator comments on private stations* NASA.

McCarty, D., & Milford, P. (2014). Uranium producer USEC files for bankruptcy protection. *Bloomberg.*

McCurdy, H. E. (2013). *The Economics of Innovation: mountaineering and the American space Program.* NASA.

Mowery, D. C. (1981). Technical change in the commercial aircraft industry, 1925-1975. *Technological Forecasting and Social Change,* (20), 347.

NASA Strategic Plan 2014 (2014). NASA. Retrieved from https://www.nasa.gov/sites/default/files/files/FY2014_NASA_SP_508c.pdf

Neis, S. M., & Klaus, D. M. (2014). Considerations toward defining medical ‘‘Levels of care’’ for commercial . *New Space, 2*(4), 165.

Orszag, P. R. (1996). *Privatization of the U.S. enrichment corporation: An economic analysis*

Overly, S. (2014, Centrus energy, formerly known as USEC, emerges from chapter 11 bankruptcy. *Washington Post*,

Passell, P. (1998, Economic scene: Selling uranium plants to enrich the private sector? *New York Times*, pp. D2.

Position paper: The NASA commercial crew program (2014). National Space Society.

Ramamurti, R. (1997). Testing the limits of privatization: Argentine railroads. *World Development, 25*, 1973-1993. Retrieved from http://search.proquest.com.proxygw.wrlc.org/docview/59791795?accountid=11243

Ramanadham, V. V. (1993). *Constraints and impacts of privatization* Routlege.

Rose, N. L. (1986). The government’s role in the commercialization of new technologies: Lessons for space policy. *RFF Proceedings*, pp. 97.

Roosevelt, Franklin D. Message to Congress Suggesting the Tennessee Valley Authority. 10 April 1933. Retrieved from http://docs.fdrlibrary.marist.edu/odtvacon.html

Russell, D.L. (2003). *Eastern Air Lines: 1926-1991*. Jefferson, NC: McFarland.

Salter, A. W., & Leeson, P. T. (2014). Celestial anarchy: A threat to outer space commerce? *CATO Journal, 34*(3), 581.

Savas, E. S. (1987). *Privatization : The key to better government* Chatham House Publishers.

Savas, E. S. (2000). *Privatization and public-private partnerships* Chatham House.

Seebass, R. (1998). History and economics of, and prospects for, commercial supersonic transport. *Fluid Dynamics Research on Supersonic Aircraft,* Rhode-Saint-Genese, Belgium.

Siceloff, S. (2014). *Commercial crew program - the essentials.* Retrieved January 04, 2015, from http://www.nasa.gov/content/commercial-crew-program-the-essentials

Smith, B. L. R. (1983). Changing public-private sector relations: A look at the united states. *Annals of the American Academy of Political and Social Science, 466*(Implementing Governmental Change), 149-164.

Spiller, J. (2014). Scientific exploration in antarctica as an analogy for american spaceflight. *Astropolitics, 12*(2-3), 180; 180-195; 195.

Stephen Miller. (2010, Updated May 13, 2010). Arms maker helped invent bazooka, led fairchild. *Wall Street Journal,*

Statement by william timbers before the house subcommittee on energy and power hearing entitled "Privatization of the united states enrichment corporation": Energy and Power, U.S. House of Representatives, 1st (1995).

Stine, G. H. (1996). Historical analogies potentially applicable to the commercialization of space activities. *Space Energy and Transportation, 1*(1)

Sweetman, B. (2014, Why we Don't have an SST. *Air & Space Magazine,*

Tennessee Valley Authority Act of 1933. 18 May 1933. Retrieved from http://www.ourdocuments.gov/document_data/pdf/doc_065.pdf

The Great Compromise. *Tennessee Valley Authority*. Retrieved from http://www.tva.gov/heritage/great_compromise/index.htm

The Origins of the Tennessee Valley Authority. *The New Deal Network*. Retrieved from http://newdeal.feri.org/tva/tva01.htm

The Tauri Group. (2014). *Emerging space: The evolving landscape of 21st century american spaceflight*. NASA Headquarters: NASA.

Thronson, H. (2013). If you set out to go to mars, go to mars! Message posted to http://www.thespacereview.com/article/2345/1

Tomain, J. P. (1987). *Nuclear power transformation* Indiana University Press.

Turnbough, L. (2012). *Commercial crew & cargo.* Retrieved in 2015, from http://www.nasa.gov/offices/c3po/about/c3po.html

U.S. enrichment corporation privatization: USEC's delays in providing data hinder DOE's oversight of the uranium decontamination agreement (2006). No. GAO-06-723)Government Accountability Office.

USEC inc. 1999 annual report (1999). USEC Inc.

USEC inc. 2011 annual report (2011). USEC Inc.

Van der Linden, F. R. (2015). *Airlines and Air Mail: The Post Office and the Birth of the Commercial Aviation Industry*. Louisville, KY: University Press of Kentucky.

Wiles, J. (2015). *About human exploration and operations.* Retrieved March 25, 2015, from http://www.nasa.gov/directorates/heo/home/about.html

Winston, C., & Yan, J. (2011). Can privatization of U.S. highways improve motorists' welfare? *Journal of Public Economics, 95*(7–8), 993-1005. doi:http://dx.doi.org.proxygw.wrlc.org/10.1016/j.jpubeco.2011.01.005

Zahariadis, N. (1995). *Markets, states, and public policy: Privatization in britain and france*. University of Michigan Press.

Zarakhovich, Y. (2000). The concordski. *Time.*