ABSTRACT

Title of Thesis: **LEADERSHIP IN PROJECTS WITH NEW TECHNOLOGY AND UNCERTAINTY**

Joseph W. Moschler, Jr
Master of Science
2021

Thesis Directed By: Professor Greg B. Baecher, Department of Civil and Environmental Engineering

Project management continues to evolve as types of projects increase, advancement of technologies available, as well as tools for project management grow in sophistication. A successful project is defined as being completed on schedule, on budget, and delivering the requirements as specified by the customer. Projects with new technologies or with technologies requiring maturation add another dimension and challenge for the project manager. Four factors are identified as integral to project success; leadership, requirements definition, technology usage and maturity, and vision and clear objectives. Three historical projects involving new technologies are evaluated within the context of the four factors: the Lockheed SR-71 Blackbird aircraft, the Hoover Dam project, and Project Apollo. The projects are qualitatively ranked as successful based on the cost, schedule, and delivering requirements criteria. The three projects were successful. Each project ranked strongly in the four factors and remain consistent indicators of potential project success.

EADERSHIP IN PROJECTS WITH NEW TECHNOLOGY AND UNCERTAINTY

by

Joseph W. Moschler, Jr.

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Master of Science
2021

Advisory Committee:

Professor Gregory Baecher, Chair
Professor John Cable
Professor Qingbin Cui

ACKNOWLEDGEMENTS

I would like to thank my advisor, Professor Greg Baecher for guiding me through this thesis process. It has been a much longer endeavor than planned, but he has encouraged me and provided the course corrections throughout. I would also like to thank my colleagues at the Defense Acquisition University for their support and advice in many areas of acquisition and project management. They have served as sounding boards, subject matter experts, and friends during this time. Finally, I wish to thank my wife Paula for her patience and understanding.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

The term Project Management is relatively new in our vocabulary, although this process has existed throughout history. From the Egyptian pyramids to modern day construction projects and large-scale information technology projects, project management is widely used to guide these accomplishments. In 1956, the American Association of Cost Engineers was established, providing a professional society for project managers, cost estimators, and schedulers, and formalized the project management term. (Haughey, 2010) This trend has continued and project management is part of the common vernacular now. Project management has taken on a larger context and continues to grow in importance as new projects increase in size, cost, and complexity. One facet of project management consistently adding difficulty is that of technology usage. Whether to achieve the edge in a competitive market, efficiency in business processes, or the advantage over your adversaries in weaponry, the use of new technologies complicates project management. Often, the success of the project may hinge on the usage of the technology to achieve its basic requirements. Other factors such as the reliance on software, information systems, and data management has added additional layers of complexity and the consequent challenge to project management. However, this research will focus on what key factors enabled projects heavily dependent on technology usage to be successful. Project management has evolved as new tools (often made possible by technologies as well) and methods advance. However, despite these advances, the realization of a successful project often is elusive with resultant cost and schedule overruns or unattained customer requirements.

An example for illustration is the current acquisition of the F-35 Lightning II aircraft by the United States' Department of Defense (DoD). The F-35, or commonly known as the Joint Strike Fighter, is produced by Lockheed-Martin Corporation and will replace several tactical aircraft used by the U.S Air Force, U.S. Navy, U.S. Marine Corps, and by numerous allied nations of the United States. Conceived as a "joint" weapon system, it was to be an aircraft with high commonality between the airframe, engine, and avionics. The aircraft would then have three variants each outfitted modular components to meet the specific needs of the three U.S. services. Originally budgeted to cost $233 billion for development and procurement, the current cost is $428 billion with a total lifecycle cost well over $1.5 trillion. (Kennedy S. , 2021) It is the single largest acquisition program ever undertaken by the Department of Defense. The aircraft has suffered significant schedule delays, scheduled to be operational with the U.S. services in 2010. At this time, it is still awaiting a decision to start full rate production with limited quantities being delivered. Although many factors have contributed to the F-35's poor track record, the aircraft's avionics, sensors, and weapon integration are very software intensive, exacerbating the technology maturity challenges and subsequent delays and cost overruns. Conversely, the worldwide pandemic caused by the outbreak of the COVID-19 virus in late 2019 has generated a massive global response to develop a vaccine to prevent the spread of the virus. In the United States, Operation Warp Speed (OWS), a cooperative program between the Department of Health and Human Services (HHS) and the DoD was launched to help accelerate the development of a COVID-19 vaccine. (Operation Warp Speed, 2021, p. 2) The OWS has been compared to Project Apollo, the U.S. led effort to "put a man on the moon within the decade" in terms of technological achievement and global impact. In nine months five of the six OWS vaccine candidates have entered phase 3 clinical trials, two of which—Moderna's and Pfizer/BioNTech's vaccines—have received an emergency use authorization from the Food and Drug Administration. (Shulkin, 2021, p. 1)

Acknowledging the acquisition of the F-35 aircraft for the U.S. military and developing a vaccine to combat a pandemic are very different projects, are there factors that can differentiate the stunning success of the OWS versus the poor performance of the F-35? Both are large scale projects, heavily dependent on innovative technologies, and require the collaboration of many stakeholders to be successful. Are there key factors that enable the success of projects leveraging new technologies?

Success has varied widely, and depends on one's perspective. Although the definition of project success will be elaborated upon within the body of this paper,

- In short, a successful project is one completed on time, on budget, and satisfying the customer's requirements.
- The critical question that may be asked is what enables a successful project? Are there key elements or attributes that increase the probability of success or are inherently responsible for a favorable project outcome?

This thesis discusses and analyzes four key factors and their relationship to project success. The description of the factors, how selected, and their importance are introduced and described in Section 1 of this work. Subsequently, specific projects chosen for the study are discussed, including background, size, cost, and whether private or public. The projects are evaluated based on the definition of success mentioned above, primarily cost, schedule, and performance (satisfying the requirements). Finally, it will be determined what correlations exist between a successful project and the selected factors.

2. WHAT DEFINES A PROJECT

A brief discussion of what defines a project and the dimensions of project management are in order. According to the Project Management Body of Knowledge (PMBOK) Guide, a project is a temporary endeavor undertaken to create a unique product, service, or result. (Project Management Institute, 2004) The temporary aspect implies the project has a definite beginning and definite end. In other words, projects are not ongoing efforts, but have a finite duration. This duration may be months or many years. As the project has a finite duration, likewise the project team generally will disband after the project is complete or terminated. A project's unique characteristics result from the different end user, different requirements, different project team or contractor, and different design or product. The PMBOK definition of a project includes product, service, or result. A product is produced, is quantifiable, and either is an end item or a component item. A service is defined as a capability to perform a service such as a business function. Examples include production, distribution, or storage. Finally, a result may be an outcome or report that documents based on a research project providing new knowledge and insights. For the purposed of this paper, the focus will be on projects classified primarily as products.

Another aspect of projects is what PMBOK refers to as progressive elaboration. Projects are completed in steps or increments. The project's scope is initially defined and as requirements and customer desires become better understood, more detailed planning occurs. When a project is developed and completed under contract, the specific work to be done must be documented and understood by both parties to the contract. This process of progressive elaboration applies to projects and supports their uniqueness.

A natural extension of projects is project management. Project management is the execution of all activities to meet the project requirements. Although, not an exhaustive list, these activities include:

- Identifying requirements
- Establishing clear and achievable objectives
- Managing the constraints of cost, schedule, and quality
- Managing the expectations of all stakeholders including changes to specifications and plans

Although these activities are critical, perhaps the most challenging one is to manage the cost, schedule, and quality. A major challenge of project management is achieving all three. An anonymous quote sums up the challenge quite succinctly, "Cost, Schedule, or performance … you can have any two, but not all three." Here performance is synonymous with quality. Known as the "iron triangle" implying if there is a change in one of three components, a corresponding change will occur to one or both of the others.

2.1. Cost

Although cost appears to be straightforward, it is a complicated subject. Cost and price are often used interchangeably when discussing this topic. In addition, for a large project, costs can be broken down into contract costs, cost of the agency or organization managing the project (*e.g.,* a government agency such as the Department of Defense), and the life cycle costs of a project incurred over its life. Does the contract cost include profit or fee? For this research, the cost elements for each project are identified to allow for analysis. The goal is to define the costs of the projects in a way to achieve a fair and unbiased comparison.

If the data is available, the cost or budget for the project will be evaluated by comparing the initial cost projection or budget to the cost at completion. The percentage over or under budget will determine the cost performance in turn used to measure overall project.

2.2. Schedule

Like cost, schedule is also not straightforward to define sufficiently for use in comparison. For many projects, the schedule may refer to an integrated master schedule or IMS. The IMS includes all activities necessary to complete the project. Usually associated with an IMS is the term ‘critical path” or the sequence of events or activities that determines when the project will be completed. Any delay or extension of an activity within the critical path will cause a corresponding delay in the overall project schedule. For the purposes of this research, the schedule will be defined as the agreed upon date for project completion between the customer and vendor/contractor. As with the aforementioned IMS, the schedule includes all activities necessary to complete the project. Similar to the use of Cost for evaluation, the original scheduled completion date will be compared to the actual delivery date of the project.

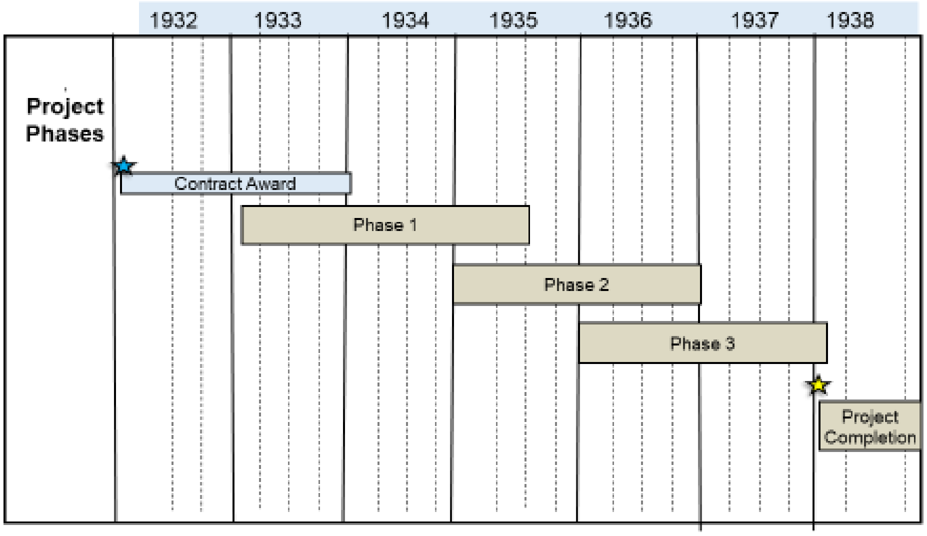


Figure 1. Schedule (Planned vs Actual)

2.3. Customer’s Requirements or Performance

Perhaps the most challenging of the three components of the “iron triangle” to define is the customer’s requirements. Also called “performance” in some areas of industry such as defense acquisition, this element is more than a project achieving a contractual set of specifications or performance parameters. Ultimately, the question is, “did the project deliver customer satisfaction?” In other words, did the project provide the needed capability, function, or system to meet the customer’s needs?

The point to be made is in some cases the project delivered to the customer “meets the spec” or more accurately all the specifications contractually agreed to, however the customer is not satisfied. This may be the result of the adage, “We built the project right, but we did not build the right thing.” Again, there are many reasons why this may occur, such as poor or unclear specifications, uncertainty by the customer in knowing the true requirements, or limited communication and interaction between customer and vendor during the project design and construction. For this research, the customer’s requirements will be presented based on historical review of the available documentation.

2.4. Definition of Project Success

What is project success? Based on the previous discussion of Cost, Schedule, and Customer Requirements, a successful project is one completed within a reasonable schedule window, stayed within the budget, and delivered customer satisfaction. However, being able to declare project success based on these criteria is not that simple. If a project was 15 percent over budget, yet was on time and delivered customer satisfaction, it too has achieved a measure of success so a method to discriminate levels of success is desirable. This research defines success criterion in the following manner (The Standish Group, 1995):

Project Success: The project is completed on-time and on-budget, with all capabilities, features, and functions as initially specified.

Project Challenged: The project is completed and operational, but over-budget, over the time estimate, and offers fewer capabilities, features, and functions as originally specified.

Project Compromised: The project is cancelled at some point during the development cycle.

3. PROJECT DESCRIPTION AND TYPE (COST, SIZE, PUBLIC *VS.* PRIVATE)

3.1. Type of Project

The projects selected are classified by categories. At a high level, these are labeled defense projects, construction projects, and aviation/space projects. The projects are further broken down by type within the categories: military weapon system, transportation related, industry, dam/water control, or space system.

3.2. Private or Public

A private project is defined as one funded by a publicly held or privately owned company or entity. Private projects are projects of every type that are owned, controlled, or commissioned by a private party. Private parties include individuals, homeowners, corporations, other business entities, non-profit associations, privately funded schools, hospitals, publicly traded companies, etc. Anything, in other words, that is not the government. (Scott Wolfe, 2013)

Public projects are funded by government or municipalities.

The term “state” can refer to projects commissioned by a county, city, municipality, government board, public school board or any other state-funded entity. The term “state construction” means, therefore, any government-funded construction that is not “federal” – which is discussed in the next section.

The difference between state and federal projects simply depends on *who* owns or controls the underlying project site. The difference is **not** which entity funds the project, because federal funds are all over state (and even private) projects. The difference is in who owns and controls the project.

3.3. Project Cost

Three descriptors with associated ranges are used to categorize Project Cost as indicated below.

Mega:	Greater than $10 Billion

Large: $1 – $10 Billion

Medium: Less than $1 Billion

All dollar amounts adjusted for inflation to 2020 (Flyvbjerg, 2014).

4. PROJECT KEY FACTORS

The present work considers fours key project factors.

4.1. Leadership

The term leadership covers an enormous range of concepts and characteristics. For the purposes of this research, leadership refers to the leadership associated with guiding or directing a project to a successful completion.

Leadership can be described as one of the “intangible” characteristics critical to a project’s success. The term itself is nebulous and conjures up a very large number of synonyms and closely related ideas. Among these are charisma, influence, vision, decision making, self-confidence, and personal energy, to name a few. Despite its fuzziness, leadership can make or break a project. There are numerous examples of project managers leaving and being replaced by a new manager with very similar qualifications. The new project manager turns the project around and makes it successful. Another aspect of leadership is the ability to manage and build relationships of trust with the project stakeholders. Perhaps difficult to describe objectively, building relationships is essential to project success.

Leadership style. Additionally, the type of project requires the leader to alter his or her leadership style. Projects pushing new technology and innovation may lend themselves to a more hands off leadership approach, one that encourages collaborative and creative thinking within the project team. On the other hand, those projects that are well defined, but have other challenges such as being of large scale or facing a high-risk schedule, may dictate a different leadership style entirely, one that relies on communication and processes. Thus, the ability of the leader to recognize the optimum leadership style for the project and implement it successfully may be the leader’s “secret sauce” of project success. As mentioned previously, this may help explain how a new project manager assuming the leadership role from a leader with similar qualifications and takes an under-performing project to a successful end.

Intellect, skill, and dedication. In some situations, the sheer intellect, skill, and dedication of the leader is the primary reason for project success. While not chosen as a project for this study, an example of a project where much of its success can be attributed to the leader is the development and construction of the U.S.S. Monitor. The Monitor was the radically new ironclad vessel built by the United States Navy during the U.S. Civil War. The Monitor dueled with the C.S.S Virginia (formerly the Merrimac), a Confederate ironclad ship on March 8, 1862 at the battle of Hampton Roads. After several hours of battle, neither ship could decisively declare victory and both withdrew from the fight. Despite the less than decisive outcome, the Union realized the Confederates did not have the ability to threaten the Union blockade of the Confederate states' seaports and harbors. The Union blockade continued, cutting off vital supplies for the war effort. This slow strangulation of incoming goods was a major factor contributing to the eventual defeat of the Confederate States.

John Ericsson, the Swedish shipbuilder who led the Monitor project, was one of the leading minds in maritime technology of his day, responsible for multiple innovations such as the screw propeller and steam engines with horizontal pistons for shipboard application. In fact, the Monitor had over 40 patentable inventions incorporated in its construction, many of them Ericsson's. (Nelson, 2004, pp. 156-157) He was literally involved in every aspect of the design, acquisition, construction, and testing of the Monitor. He personally managed the acquisition of the materials and construction of the ship, visiting the different construction sites to monitor progress and lend his expertise to overcome technical issues. He developed relationships with the key stakeholders such as the U.S. Navy, and subsequently updated or revised requirements based on their feedback. Some of these changes were made only after Ericsson had to be swayed through operational testing (and sometimes at high risk), but ultimately improved the performance. He knew every subcontractor and vendor supplying materials for the ship, visiting and communicating with each frequently. Under his leadership, the U.S.S. Monitor was built and delivered to the U.S. Navy in less than 100 days, as required by the contract. John Ericsson was the lynchpin for the Monitor's noteworthy success.

Figure 2. John Ericsson National Memorial, The Mall, Washington, D.C.
(courtesy, Wikipedia, Creative Commons).

The Leadership project factor will be evaluated using a rating scale considering the capability and effectiveness of leadership for as defined in Table 1.

Rating Factor	Rating Description
Exemplary	Role Model/Best in Class
Superior	Very Capable and Effective

Adequate	Capable and Effective
Marginal	Somewhat Effective
Unsatisfactory	Needs Development

Figure 3. Leadership Factor Rating Scale

4.2. Requirements Definition

There is urban legend about customers with the attitude of “Bring me another rock” when it comes to meeting their expectations for a product or solution. In other words, the customer cannot clearly express their requirements, hoping the contractor will provide the solution based on minimal information. This scenario is not favorable for a successful project. The customer/client and the project team must be in lockstep throughout the requirements definition process for the project.

Requirements definition is a process essential to project success. If the customer’s requirements are not well defined, stable, and traceable, the probability of completing the project on time and within budget is unlikely. To that end, an active relationship between the project team and customer with frequent communication and interaction allows for the necessary discussion on cost, schedule, and performance tradeoffs that will invariably occur during a project. This relationship facilitates the dialogue on priorities of customer requirements, where the customer is flexible, and where not. Determining the customer’s requirements from the start is critical. Defining requirements is hard work, demanding thoughtful discussion among the stakeholders. The ideal requirements have the following characteristics: specific, unambiguous, performance-based, achievable, verifiable, complete, and traceable back to the original need. Other more overarching desirable attributes of requirements are stability, singular goal, and balanced with requirements flexibility from the stakeholders. A definition of derived requirements is appropriate in this discussion. Derived requirements are those are not explicitly stated in the set of stakeholder requirements yet is required to satisfy one or more of them. They also arise from constraints, consideration of issues implied but not explicitly stated in the requirements baseline, factors introduced by the selected architecture. (Requirements Development, 2018) Derived requirements drive the complexity and breadth of the overall requirements associated with a project. In addition to the basic set of customer or stakeholder requirements, there are derived and those resulting from statutes, regulations, and design considerations.

Related to the concept of requirements definition is Project Scope. According to the PMBOK, defining and managing the project scope influence the project's overall success. Project scope is defined as the work to be accomplished in order to deliver a product, service, or result with the specified features and functions. (Project Management Institute, 2004)

The project scope statement is critical to success and builds upon the major deliverables, assumptions, and constraints documented during project initiation. As the project evolves, other tools such as the Work Breakdown Structure (WBS) will be generated and used to document and manage the project scope.

An example of how poor requirements definition can doom a project is the fate of the U.S. Air Force's Expeditionary Combat Supply System (ECSS). Envisioned to transform the management of Air Force global logistics and supply chain network in support of worldwide operations, the ECSS was an integrated software platform developed to replace hundreds of legacy disparate computer systems. Launched in 2004, the Air Force was initially enthusiastic about the new integrated logistics concept that would make operations more efficient and effective, but the program was fraught with problems. Indeed, eight years into the program, the Secretary of

Defense cancelled the ECSS program after $1 billion spent. To make matters worse, the investment did not provide any useable capability. After the cancellation, the Air Force reverted to using the legacy systems that the ECSS program was supposed to replace and continues to use them today. What led to such a colossal failure of the program? Prior to the program's inception, the Air Force did not adequately plan for its acquisition. Most notably, the Air Force had only a top-level idea of what capability the ECSS would deliver; a new, fully integrated logistics system that would replace an unspecified number of older, unconnected logistics systems. (United States Senate Permanent Committee on Investigations Committee on Homeland Security and Governmental Affairs , 2014)

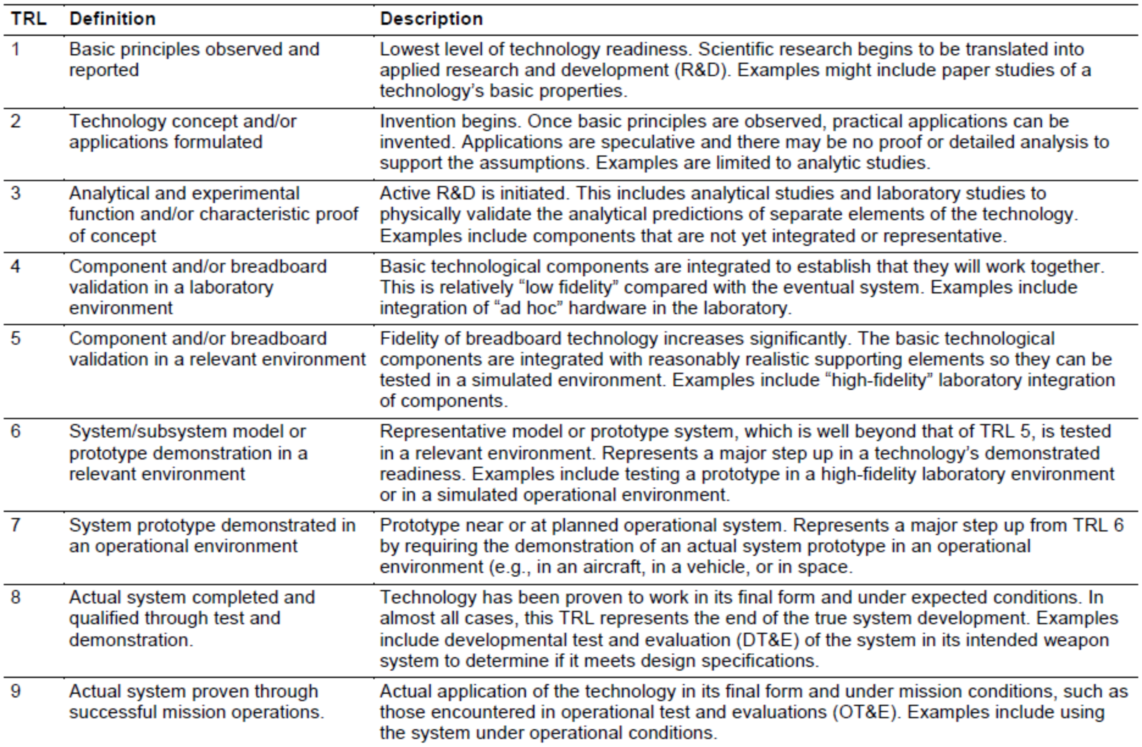
The Air Force failed to define specific, achievable, and traceable requirements for the ECSS. As a result, the original solicitation for bids to contractors was vague and incomplete in many areas. The poor requirements definition up front and the lack of direction from the key stakeholders in the Air Force were major contributors to the program's failure. Answering the question "What capabilities do I really need?" is key to success for any project.

The Requirements Definition for each project will be evaluated primarily based on how well defined and stable the requirements remained through the project lifecycle. It is unrealistic to consider all requirements, and the top level or "system" level requirements will be evaluated qualitatively.

4.3. Technology Usage and Maturity

Projects using or depending on new technologies with questionable maturity pose serious challenges to program success and often lead to delays, cost overruns and failure or cancellation. The uncertainty of technology maturity has played a role in many projects, driving cost and schedule issues, particularly in the Department of Defense and other government agencies. The old adage "If you want it bad, you will get it bad" is usually born out in these situations. More to the point, poor performance or cancellation of projects results from rushing technology usage on systems or products before adequately matured and tested in realistic environments and representative levels of usage.

Technology Readiness Levels. Determining technological maturity or readiness is challenging with many variables and factors for consideration in order to provide the necessary insight to project leaders. One methodology to assess technology readiness within governmental organization such as the National Aeronautics and Space Administration (NASA) and the Department of Defense is the use of the Technology Readiness Levels or TRLs. Technology Readiness Levels, originally developed by NASA, help assess the maturity of specific technologies using a numerical scale ranging from "1" to "9." For technology ranked at TRL 1, scientific research is beginning and the results translated into future research and development efforts. On the other hand, technology assessed to be TRL 9 has been proven through operational use in the intended environment. (Office of the Director, Defense Research and Engineering, 2009). Although not a foolproof method of assessing technology maturity, it is a tool for applying objective measurements to new technologies under consideration. However, it does not provide insight on the difficulty involved with maturing the technology to the appropriate level for use in the associated project. However, it does provide a departure point for project managers to discuss the risks of the use of the new technology.



TRL	Definition	Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or applications formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental function and/or characteristic proof of concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in a laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5	Component and/or breadboard validation in a relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstrated in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring the demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space.
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of the true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluations (OT&E). Examples include using the system under operational conditions.

Figure 4. DoD Technology Readiness Levels from U.S. Government
Accountability Office (GAO-20-48G, January 2020)

Gartner hype cycle. A second methodology for assess technology uses the Gartner hype cycle to characterize the cycle of application of new technologies. The hype cycle has five steps:

Technology Trigger: event such as the announcement of a breakthrough or product launch that generates interest with the public, businesses, and organizations

Peak of Inflated Expectations: Publicity may result in unrealistic expectations and over enthusiastic promotion

Trough of Disillusionment: Because the technologies fail to meet expectations, they may be abandoned

Slope of Enlightenment: Despite being abandoned by some, other users continue to experiment and learn to understand the benefits and practical uses of the technology

Plateau of Productivity: More widespread adoption is occurring. The broad market relevance and application are being evident.

(The Mitre Corporation)

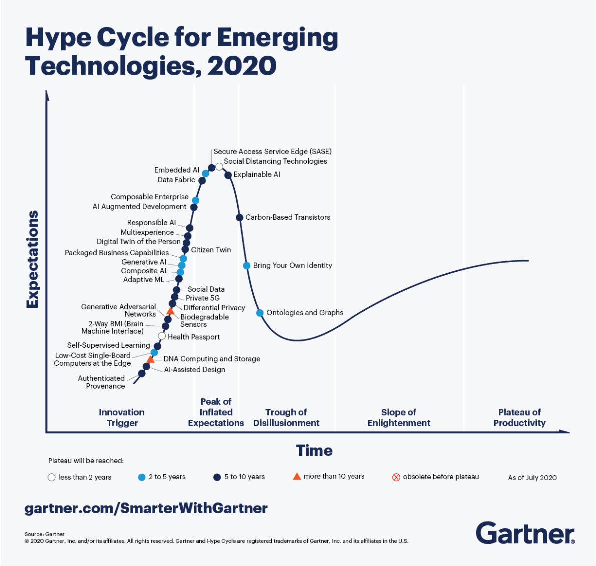


Figure 5. Example of the Gartner Hype Cycle™
(https://www.gartner.com/smarterwithgartner/5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020/)

The Gartner hype cycle approach may be viewed as less rigorous than the use of TRLs; however, it may prevent organizations investing in technologies that may not be suitable for the customer. For example, when project stakeholders other than the customer promote the technology before its appropriate assessment of maturity and relevance putting project funding at risk.

An example of a project where the underestimation of the technology challenge was a major factor in its eventual cancellation was the U.S. Navy's A-12 aircraft. In the mid 1980's the Navy embarked on an ambitious project to develop and build a new carrier based medium range attack aircraft. Importantly, the aircraft was to have "stealth" or low observable characteristics, making it difficult to detect by enemy radars. Although the U.S. Air Force was already operating stealth aircraft, the technology was still new in the industry, resulting in many challenges for the design, integration, and manufacture of air vehicles. The requirement for the aircraft to take off and land from an aircraft carrier further complicated the project with additional structural design considerations.

Figure 6. Artist's impression of the A-12 Avenger II in flight
(https://en.wikipedia.org/wiki/McDonnell_Douglas_A-12_Avenger_II)

Designated the A-12 Avenger, the project was in trouble within two years of contract award with costs soaring $500 million over budget and estimated to be two years behind the original schedule. The two contractors building the A-12 claimed they did not have access to the technology information to complete the project and could not meet the requirements of the contract. Subsequently, the Secretary of Defense cancelled the A-12 project in 1991, four years after contract award. The Department of Defense and the two contractors ended up in litigation for nearly 23 years over who was to blame for the failure. As with many large project failures, many factors contributed to the cancellation of the A-12, but the immaturity of stealth technology for this application proved to be a principal cause. (Report on the Review of the A-12 Aircraft Program (Report #91-059), 1991) The Technology Usage and Maturity for each project will be discussed qualitatively considering the number of technical challenges involved, what new technologies were required, and level of maturity.

4.4. Vision and Clear Objectives

The vision for a project (and team) must be understandable and concise. A well-known quote from the former CEO of Kodak Imaging, Bruce Swinsky, states “But good leaders simplify.” Arguably, this an important part of the project leader’s role. Usually the leadership of corporations, government agencies, or the military services will define the specific terms of the project. Ultimately, the project manager should have the latitude and discretion to define a vision to meet those terms and requirements. Although technically not the project manager, President John F. Kennedy set a clear vision for the nation’s space program when he spoke to a Joint Session of Congress on May 25, 1961. His extraordinary goal of sending a man safely to the moon and back within the decade serves as a superb example of setting a clear objective; concise, simple, and easy to understand. In his address, he said, “I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth.” (Kennedy, 1961). Although this example of a vision statement may be significantly beyond that of most projects in impact, cost, and effort, it illustrates the point of how critical a clear vision is to a project’s success. How does one measure “Vision and Clear Objectives?” For this research, each project’s vision and objectives will be evaluated through the consideration of clarity, ambitiousness, and realism.

5. THE LOCKHEED SR-71 BLACKBIRD

Three case studies from large federal projects are used to analysis: The Lockheed SR-71 Blackbird, Hoover Dam, and Project Apollo.

In the 1950's the Cold War between the United States and the Soviet Union was escalating. In an effort to monitor the Soviet Union's progress in developing nuclear weapons and military facilities, the U.S employed satellites and manned aircraft for surveillance. The Lockheed U-2 aircraft was developed as a high-flying reconnaissance platform to gather intelligence for the United States and first flew in 1955. These aircraft, operated by the Central Intelligence Agency (CIA), flew at altitudes in excess of 70,000 feet, above the ceiling of the Soviet's air defense system of radars and surface to air missiles (SAM). However, U.S intelligence were concerned of the advances in Soviet technology and recognized the U-2 was increasingly vulnerable.

On 1 May 1960, this fear was realized when Francis Gary Powers' U-2 was shot down by a SA-2 Guideline missile. Although uninjured, Powers was captured, tried for espionage, and sentenced to 10 years of prison and hard labor. He did not serve the full term as he was released in return for captured Soviet spy Rudolf Abel and returned to the United States. (U-2 Overflights and the Capture of Francis Gary Powers, 1960, 2020). The embarrassing event confirmed what U.S. intelligence agencies suspected; the consistent and potent advances in the Soviet air defenses. Fortunately, the U.S Air Force (USAF) and the CIA were engaged in a project to develop an aircraft that could both out run and out fly the Soviet Union air defense missiles and interceptors.

Figure 7. Lockheed SR-71 Blackbird (https://airandspace.si.edu/collection-objects/lockheed-sr-71-blackbird/nasm_A19920072000

At Lockheed, studies had been underway to improve the survivability of the U-2 aircraft by improving its maximum ceiling, use of enhanced electronic counter measures, and reducing its radar and infrared signatures. (Johnson, 1981). However, none of the measures were considered sufficient to provide the necessary improvement to the survivability of the U-2 against the increasingly capable Soviet threats. In response, a new manned aircraft design was underway that would travel at speeds in excess of Mach 3 (3 times the speed of sound) and fly at altitudes above 80,000 feet to avoid the Soviet air defenses. It would have a minimal radar cross section to help avoid detection and sophisticated electronic countermeasures for employment when detected. An air vehicle with such capabilities had never been built and faced numerous technical challenges.

5.1. Leadership

Clarence “Kelly” Johnson, the manager of the Lockheed Advanced Development Projects Division or more commonly known as the “Skunk Works” was the man tasked to lead the effort.

Kelly Johnson was a veteran manager of similar projects at Lockheed including the P-38 fighter, F-80 jet fighter, and the previously mentioned U-2 reconnaissance aircraft. In fact, Johnson had a role in the design of more than 40 aircraft while at Lockheed. Kelly Johnson, known for his near charismatic leadership style, started and managed the Skunk Works using “a concentration of a few good people … applying the simplest, most straightforward methods possible to develop and produce new products with minimum overhead and outside oversight.” He further said, “Our aim is to get results cheaper, sooner, and better through application of common sense to tough problems. If it works, don’t fix it” (Rich, 1995). His leadership was legendary and many of Johnson’s employees turned down promotions within Lockheed to stay on his team at the Skunk Works. With a proven track record, a high performing team, and strong stakeholder backing from the United States Air Force and the Central Intelligence Agency, Kelly Johnson was a natural to lead the SR-71 development effort. Kelly Johnson is given much credit for his leadership of the Lockheed team and deservedly so.

However, the team included more than Lockheed. Pratt and Whitney designed and built the J-58 engine that powered the SR-71 aircraft. Although Lockheed was the prime contractor, Pratt and Whitney’s engine design was key to the success of the aircraft and overall project. William Brown, the Engineering Manager at Pratt and Whitney, recognized the unique teaming between Lockheed his company. During a presentation at an American Institute of Aeronautics and Astronautics in 1981, he said, “As you have probably noticed, I have had difficulty in differentiating between “we” Pratt and Whitney Aircraft and "we” Lockheed. But that is the kind of program it was.” so great was the sense of collaboration and teamwork between the two companies. (Brown, 1981) Additionally, the government team’s approach to management was an enabler to the success of the project. A statement also attributed to Mr. Brown illustrates that sentiment. He made the following statement, “That this complex, difficult program was successful is attributable in large part, to the management philosophy adopted by the Government people in charge. Their approach was that both the engine and airframe contractors must be free to take the actions, which in their judgment were required to solve problems. The Government management of the program was handled by no more than a dozen highly qualified and capable individuals who were oriented toward understanding the problems and approaches to solutions, rather than toward substituting their judgment for that of the contractors. Requirements for Government approval as a prerequisite to action were minimal and were limited to those changes involving significant cost or operational impact. As a result, reactions to problems were exceptionally quick. In this manner, the time from formal release of engineering paperwork to the conversion to hardware was drastically shortened. This not only accelerated the progress of the program, but saved many dollars by incorporating the changes while the number of units were still relatively small.” The leadership of Kelly Johnson at Lockheed and William Brown at Pratt and Whitney were key success factors to the program’s success. However, as Brown stated, the close working relationship demonstrated by the contractor and government team must be recognized. In total, over 300 subcontractors and vendors supported the program.

Rating: Exemplary – proven track record, high performing team, high trust relationship between government and contractors.

5.2. Requirements Definition

The requirements for the Blackbird were challenging to achieve at the time, but were straightforward: go fast and fly high and not fall to enemy defenses. More specifically, the aircraft needed to provide a stable and reliable platform to gather photographic and other intelligence information for the United States and be invulnerable to enemy air defenses. As stated previously, the aircraft would have to fly at Mach 3+ speeds at altitudes above 80,000 feet for extended mission times. The aircraft's radar cross section would need to be as small as possible to avoid detection by air defense radars and employ electronic counter measures as needed. The derived requirements and technological challenge to achieve these goals were enormous, but overall the requirements set was stable and well defined.

Rating: Well-defined, very specific mission, traceable to the customer

5.3. Technology Usage and Maturity

Because of the projected airspeeds in excess of Mach 3, the aircraft had to withstand temperature extremes beyond any aircraft yet built. Aircraft structures, wing skins, canopies, crew escape systems, radomes, and even fuel, lubricants, and hydraulic fluids would all require specialized designs or formulations to withstand the high operating temperatures during flight. Engine technology to date had enabled speeds up to 2,000 miles per hour, but only in short bursts. This aircraft would require this speed and beyond for sustained periods, often hours at a time. To produce the power required, the J-58 Pratt and Whitney engines developed for the aircraft functioned as ordinary turbojets at lower speeds, but transitioned to ramjets at speeds above 2,000 mph. (Bennie J. Davis, 2017)

"Everything had to be invented. Everything." is a quote attributed to Kelly Johnson when recalling the development of the SR-71 aircraft. Although the TRL methodology described earlier was not applied to the SR-71 technical challenges (TRLs did not exist then), it is possible to make some general observations about what the project faced.

New tooling for the complex materials used had to be developed as titanium proved challenging for machining and handling. Lockheed launched a complete research program to determine the best tool cutter designs, cutting fluids, and speeds and feeds for the best metal removal rates.

(Johnson, 1981) A new quality control program was developed and implemented because of the more complex and demanding materials and manufacturing processes.

New test fixtures and test methods were designed to test the components, subsystems and systems for the aircraft in the environments it would operate. A large oven had to be constructed to test the forward fuselage and cockpit (made up of over 6,000 parts) for thermal effects at the expected operating temperatures. Instrumentation did not exist to gather real time measurements, thus had to be developed to survive the hostile test conditions.

Rating: the technology challenges were daunting for the aircraft. It would be in a new category for speed, altitude, and endurance. Aside from the Apollo space program, the technology hurdles were some of the most difficult facing the aerospace industry. Coupled with the aggressive delivery schedule, the success of the SR-71 program was a remarkable achievement.

5.4. Vision and Clear Objectives

The Soviet threat posed a real and unquestioned threat to the US and its allies. As early as 1955, officials in both Moscow and Washington had grown concerned about the relative nuclear capabilities of the Soviet Union and the United States. Given the threat that the nuclear arms race posed to national security, leadership in both countries placed a priority on information about the other side's progress through monitoring. The surveillance provided by aircraft such as the U-2 and satellite assets provided United States intelligence agencies essential information to keep tab on Soviet nuclear capabilities. Once the vulnerabilities of the U-2 reconnaissance aircraft were identified, the need for a more capable manned platform became paramount. This translated into the need for an aircraft similar to the SR-71: a surveillance platform that could be rapidly deployed to the point of need to gather intelligence for the United States. William H. Brown, a Pratt and Whitney Engineering Manager in the program, summarized the issue this way; "The

Government stated that the need for the Blackbird was so great that the program had to be conducted despite the risks and the technological challenge. " (Brown, 1981)

Rating: The key components for a vision were there. That is the Who, What, How, When, and Goal. The United States (USAF, CIA, aerospace industry) stakeholders were tasked to build a high performing aircraft to conduct reconnaissance of the Soviet Union nuclear capabilities as soon as possible as a follow on to the high flying, but vulnerable U-2.

5.5. Cost, Schedule & Performance:

SR-71 Cost/Schedule/Performance:

Cost: $34 Million per aircraft ($250 Million in current dollars) 32 aircraft were built

Schedule: 30 months from approval to design, produce, and test to first flight of the A-12 (early version of SR-71). (32 months later, the first flight of the SR-71 took place, approximately five years from the project start.

Note: The cost for the research, development, and test of the A-12/SR-71 project are not readily available

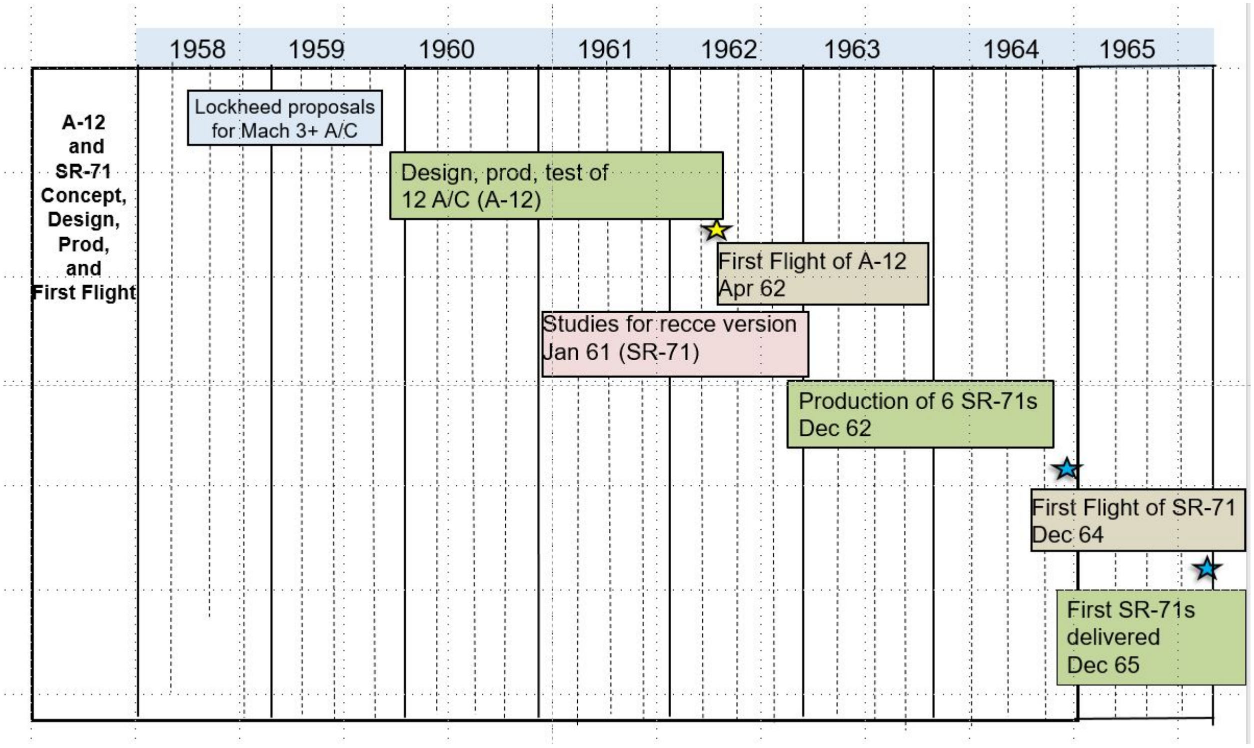


Figure 8. A-12/SR-71 Design, Production, Test, and Delivery

The SR-71 flew non-stop from New York City to London in 1 hour and 55 minutes, then back to northern California for a round trip time of 3 hours and 48 minutes. It was, and still is the fastest and highest-flying aircraft in the world. More importantly, no SR-71 was ever lost due to enemy action. Of the numerous missions flown during the programs' operational lifetimes, no nation ever shot down—or came close to intercepting—an A-12 or SR-71. (Santucci, 2013) Finally, it provided surveillance information on our adversaries to the nation's intelligence agencies and decision makers for nearly 30 years.

6. THE HOOVER DAM

The Hoover Dam was the largest dam, public project, and government contract in United States history when awarded in March 1931. (Smith, 2008) The Hoover Dam and Lake Mead behind it are located in the Black Canyon of the Colorado River about 35 miles southeast of Las Vegas, Nevada. The dam is a concrete thick-arch structure, 726 feet high and 1,244 feet long. The Hoover Dam is indeed a massive structure. It was the first man-made structure to exceed the masonry mass of the Great Pyramid of Giza. The dam contains enough concrete to pave a strip 16 feet wide and 8 inches thick from San Francisco to New York City, or 3.25 million cubic yards of concrete. (Simonds, 2009) The dam was to serve four functions: produce hydroelectric power, flood control, silt control, and water storage. It can be argued that it served a fifth purpose; a source of jobs for many unemployed workers due to the Great Depression. Both Presidents Herbert Hoover and Franklin Roosevelt heralded the many jobs generated by the project.

Figure 9. The Hoover Dam (https://www.usbr.gov/lc/hooverdam/

The Colorado River had long caused flood devastation as snowmelt from the Rocky Mountains flowed through the Boulder Canyon. In 1905, flooding was so great the river flowed into the Imperial Valley of California for over a year and created a new body of water named the Salton Sea. The formation of the Salton Sea actually took place over several months as portions of the irrigation system that fed the agricultural area were compromised. In late November of that year, heavy flooding from the Gila River flowed into the Colorado River threatening the entire Imperial Valley. Despite efforts to reroute the Colorado onto its previous course, the summer floods in 1906 overwhelmed the works and inundated thousands of acres of crops, covered or damaged towns, and submerged miles of the Southern Pacific railroad. The Salton Sea grew to over 400 square miles. (Kennan, 1917)

President Herbert Hoover had visited the lower Colorado River on numerous occasions during the early 1900's. He was well aware of the challenges due to the flooding as previously mentioned, but also the opportunities it presented. He became the Secretary of Commerce in 1921 and soon after presented the idea of a dam in the Boulder Canyon. The dam would provide hydroelectric power to the region, provide a water source to southern California, allow for expansion of irrigation for agriculture, and importantly help with flood control. Despite the many benefits of Hoover's proposal (including the potential of the dam paying for itself by selling electrical power), several major obstacles existed. Perhaps the most problematic was that of water rights of the many states in the Colorado River basin affected by the dam project. The Colorado River Commission was formed in January 1922 at Hoover's urging to solve the water rights issue. He proposed the Colorado River water resources to be divided into two groups, the Upper and Lower Basin States, with the division of water within each Basin to be negotiated later. The Upper Basin consisted of Colorado, Wyoming, Utah, New Mexico and a portion of

Arizona (portions of Arizona are in both Upper and Lower Basins). The Lower Basin consisted of California, Nevada, and part of Arizona. Hoover helped broker a compromise and finally on November 24, 1922 the commission agreed upon the Colorado River Compact. Six of the Basin states signed the compact along with the Federal government; Arizona did not sign until 1944. Despite the lack of Arizona's support, the Colorado River Compact did pave the way for a dam in Boulder Canyon. However, it would take several years of introduction and reintroduction of bills in Congress to gain approval to start construction. Finally, in 1928, both the House and Senate approved a bill and President Calvin Coolidge signed it in December of that year. However, Herbert Hoover defeated Coolidge in the presidential election, replacing him in 1929. As the new president, he oversaw the formalization of the Colorado River Compact and the start of construction of the dam in 1931. Unfortunately, President Hoover was not able to see the project to fruition as Franklin D. Roosevelt defeated him in the 1932 presidential election. President Hoover did make a final visit to the construction site in November 1932 to pay tribute to the builders and highlighted the far-reaching impacts the dam would have on the region. His words proved to be accurate.

6.1. Leadership

The Hoover Dam was designed and built by the consortium called Six Companies, made up of construction giants Bechtel and Henry J. Kaiser, Morris-Knudsen, J.F. Shea Company, Pacific Bridge Company, MacDonald & Kahn, Limited, and Utah Construction. Six Companies banded together because no single company was could raise the $5 million required to secure the performance bond. (Hoover Dam: A Project for the Ages, 2020) The major tasks required of Six Companies were construction of the following: four tunnels to redirect the Colorado River, two spillways, four intake towers, the dam, two power stations, and two waterworks buildings. The tunnels had to be completed within 2 ½ years of contract award to allow for construction of the dam. The dam was to be finished within seven years. (Smith, 2008) Beyond pooling resources to secure the performance bond, each company making up the Six Companies consortium brought a unique skill set to the table. J.F. Shea, a plumbing company, had extensive experience in constructing tunnels and other underground work. Utah Construction had built railroads in the western United States and Mexico. McDonald and Kahn had built many large buildings in San Francisco and Betchtel was known for road building. In addition to the contract awarded to Six Companies, several other ancillary contracts were issued. The Allis-Chalmers Company held the contract to build the power turbines for the electrical generators. Both General Electric and Westinghouse Electric were would provide the 82,500-Kilowatt generators. Babcock and Wilcox would provide the 14,000 feet of plate steel piping supplying water to the turbines and outlet works. The Union Pacific Railroad built and operated a 22.7-mile rail line from Boulder City to a point just south of Las Vegas. Power companies (Southern Sierras Power and the Nevada-California Power Company) built a 222-mile power transmission line to provide power to the construction site and then after completion of the dam, to carry power from the dam to areas of Southern California. To house and support the 5,000 workers and their families, Boulder City was constructed. The town was planned using the accepted standards for municipal development and was constructed with paved streets, a water and sewer system, electrical power, a city hall, administrative building, schools, a hospital, and houses for the workers and their families. (Simonds, 2009)

One of the leading dam builders in the United States during the Hoover Dam era was Frank T. Crowe. He had spent twenty years working for the Department of Reclamation and for private construction companies. His projects included the Arrowrock Dam in Idaho, the Jackson Lake

Dam in Wyoming, and the Tieton Dam in the state of Washington. Well known for his ingenuity, he developed a system of transporting concrete and equipment using a cableway system. Later, his mechanical prowess would be of great benefit on the Hoover Dam project. Prior to 1925, the Bureau of Reclamation (previously known as the Reclamation Service) was heavily involved in dam building projects. However, in 1925 it began contracting such projects out to private companies. Mr. Crowe had been involved in early planning on a dam for the lower Colorado River, assisting the Reclamation Commissioner, Arthur Powell Davis with cost estimating for the project and later with preliminary design work. He was deeply invested in the project and anxious to see it through to completion. He faced a dilemma when the Department began contracting out this type of project. In order to be a part of the Hoover Dam project, he elected to leave the Department of Reclamation and hire on with a private construction company. In 1924 (need to confirm) he joined the Morrison-Knudsen Company and immediately became an influential player. His vast experience with the government in dam building and the cost estimation process proved valuable and he helped Six Companies develop the winning bid for the Hoover Dam project. Six Companies made a bid of $48.9 million for the project, just $24,000 higher than the Department of the Interior had budgeted and $10 million below the next lowest bid. (Hoover Dam: A Project for the Ages, 2020) Six Companies won the contract on March 4, 1931 and named Frank Crowe the construction superintendent.

Frank Crowe’s nickname was “Hurry Up” Crowe, earned by his drive and determination to get the job done. This characteristic may have influenced decisions to place the project success and schedule ahead of the welfare of the workers. For instance, during the construction of the four diversion tunnels, Six Companies allowed the operation of gasoline powered trucks during excavation of the tunnels in direct violation of Nevada state law. In the poorly ventilated tunnels, this practice made carbon monoxide poisoning a constant concern, endangering the workers. The state of Nevada sued Six Companies to stop the practice, but were unsuccessful. Crowe and Six Companies obtained a restraining order allowing the practice to continue until the case could be heard in federal court. In April 1932, a panel of federal judges ruled on the case and found in favor of the company. By this time, most of the tunnel construction was completed anyway and was essentially a moot point, but nonetheless a victory for Frank Crowe and Six Companies. (McBride, 1999) In another instance, a labor strike took place during August of 1931 due to poor working conditions. Among their grievances were excessive heat in the tunnels (at times above 130 degrees Fahrenheit), poor drinking water, and a lack of proper safety precautions. Instead of attempting to improve conditions, Crowe and Six Companies blamed agitators for the unrest and turned to unemployed workers clamoring to take the place of the strikers. In reality, conditions were dangerous for the workers constructing the dam. During July 1931, fifteen men are documented to have died, some attributed to heat prostration. However, Crowe denied any deaths occurred as a direct result of working on the construction site. Due to his actions, he was deemed a "company man." Nonetheless, his vision, mechanical ingenuity, and dedication to the project were key factors for success. Under Frank Crowe's leadership, construction of the Hoover Dam completed two years ahead of schedule. On Feb. 29, 1936, Crowe handed the finished project over to the Bureau of Reclamation.

Rating: Superior – highly experienced, innovative and knowledgeable leaders, competent execution of the contract requirements while employing some noted questionable practices

6.2. Requirements Definition

The requirements for the Hoover Dam were stable and well defined. The specific tasks are mentioned in the Leadership section, but are repeated here for consistency. The major tasks required of Six Companies were to construct the following: four tunnels to redirect the Colorado River, two spillways, four intake towers, the dam, two power stations, and two waterworks buildings. The diversion tunnels had to be completed within 2 ½ years of contract award and the dam within seven years. (Smith, 2008) Due to the remote location and lack of nearby towns, many derived requirements evolved. Also previously mentioned, the project required housing and facilities to support the 5,000 workers and families. Transportation systems (roads and railroads) and electrical power distribution was needed to support the construction.

Rating: Well-defined, stable requirements delineated in the contract awarded to Six Companies.

6.3. Technology Usage and Maturity

One of the major challenges of design and construction of the Hoover Dam was the sheer size and scale of the project. Prior to the proposed dam in Black Canyon, the highest dam in the world was the Arrowrock Dam in Idaho. At just over 348 feet high, Arrowrock Dam was less than half the height of the proposed dam, which would be the Hoover Dam. Before the dam could be built, solutions to several construction complications would have to be found and implemented. (Simonds, 2009) The construction site itself was located in a remote location requiring extensive work to provide transportation of equipment and materials, communication, sources of electrical power, and housing for the 5,000 workers and their families. Although none of these construction support efforts were considered novel, the scale and austere conditions at the construction site made them major and difficult tasks. The distances from major towns and the magnitude of the construction materials to be used required railroads, roads, power transmission lines, and other support facilities built in harsh environments. The terrain was rugged, rocky, with steep grades. The climate was equally severe, with temperatures exceeding 100 degrees Fahrenheit 24 hours continuously in the valley where the dam was to be located. To help transport the enormous amount of construction materials and equipment to the dam site, a 150-ton capacity cableway was built, spanning the canyon just below where the powerhouses that would be eventually located. As mentioned in the Leadership section, Frank Crowe pioneered the same technology to improve the efficiency and speed of construction for large dams. In 1911, while working on construction of the Arrowrock Dam in Idaho, he developed two practices that proved pivotal in the building of superdams. The first was a pipe grid used to transport cement pneumatically, the second was an overhead cableway system employed to deliver workers, equipment, and concrete rapidly to any point on a construction site. (Chief Engineer: Frank Crowe, 1999) Both these techniques paid great dividends during the Hoover Dam project due to the extensive amounts of concrete required and the sheer size of the construction site.

Another challenge with using the massive amounts of concrete required for the dam, was removing the heat generated by the concrete curing or hardening process. Concrete pouring generates heat as it creates an exothermic reaction. The heat produced by concrete during curing, called" heat of hydration" occurs when water and cement react. If the temperature of the concrete is too hot during hydration, it will have high early strength, but less later in development resulting in lower durability of the concrete. Additionally in large mass concrete pours such as those in the Hoover Dam, the internal temperatures may be much higher than that of the surface. The large temperature gradient may result in thermal cracking. (The Importance of Concrete Temperature Gradients, 2020) Due to the sheer magnitude of concrete required for the dam and its associated structures, the levels of generated heat were a major concern. To reduce the cooling and contraction time, an artificial cooling system was employed. A system of embedded pipe loops with refrigerated water flowing through them was successfully tested by the Bureau of

Reclamation at the Owyhee Dam in Idaho in 1931, two years before concrete placement started on the Boulder Dam project. (Simonds, 2009) For the Boulder Dam, a dedicated cooling tower and refrigeration plant were constructed on site and began operation in August 1933. Carried out in two stages, air- cooled water was circulated through the tubes followed by refrigerated water through the same tubes. In May 1935, when most of the concrete pours were completed and the cooling operations terminated, more than 590 miles of pipe was embedded in the dam with over 159 billion BTUs of heat removed. (Simonds, 2009)

A final aspect of Technology Usage and Maturity discussed is the formation of the Six Companies. Although not specifically a technical advance, the companies forming together and pooling their resources and expertise was innovative. The companies joined forces because no one company could afford the cost of the performance bond, but this allowed them all to share the risk and their talents. This proved to be a successful model for large construction projects and has been widely used to this day. Indeed, the Bechtel Engineering Company (then known as Henry J. Kaiser & W. A. Bechtel Company) deems it the world's first "megaproject."

Rating: The technology challenges in constructing the Hoover Dam were very different to those the SR-71 program faced. Large construction projects using massive amounts of concrete were not unheard of this era. Nevertheless, the challenges posed by the Hoover Dam were the harsh environment, the distance of the site from a city or town to offer support, and the enormous quantity of concrete required for the dam, tunnel complex, and powerhouses. At 726 feet high and 1,244 feet long, the Hoover Dam was the largest dam built in the United States when completed. During construction, no extraordinary technology was employed, but the builders did use innovative approaches to improve efficiency and speed of the construction such as the cooling system and the concrete and material delivery system. At the dedication of the dam on

September 30, 1935, President Franklin Roosevelt referred to the dam as "an engineering victory of the first order - another great achievement of American resourcefulness, skill and determination." It was and still is an engineering marvel.

6.4. Vision and Clear Objectives

Many recognized the Colorado River as a potential water source for irrigation of land in California's Imperial Valley for many years. During the 1850's ideas for that purpose were discussed, but no real development started until the turn of the century. In 1896, the California Development Company began constructing canals in the Imperial Valley and the first water from the Colorado River was delivered in 1901. (Simonds, 2009) As discussed in the Hoover Dam opening section, the flooding of the Imperial Valley in the early 1900's was so destructive that farmers, landowners, and area residents turned to the U.S. government for relief. Other areas affected by flooding of the Colorado River and its tributaries sought help as well, such as Yuma, Arizona. As a result, the Bureau of Reclamation began study of how to tame the river and take advantage of its resources.

Although not a new idea, Herbert Hoover championed the idea of a dam project to help control the unpredictable floodwaters from the river as well as produce electric power and provide irrigation to the region. He is often credited for bringing the project to fruition, particularly in his role as Secretary of Commerce when he helped craft the Colorado River Compact.

Rating: the Hoover Dam project was an audacious and courageous undertaking. (Hoover Dam: A Project for the Ages, 2020) Long recognized as a way to restrain the flood prone Colorado River, the dam served multiple purposes as previously mentioned and provided thousands of jobs during the Great Depression. Ultimately, the vision and objective was concise, simple, and easy to understand.

6.5. Cost, Schedule & Performance

Cost: just under$49M, or $860M today the project was completed on budget

Schedule: Contract was awarded in March 1931 and turned over to the Bureau of Reclamation in February 1936 after five years of construction (2 years ahead of schedule)

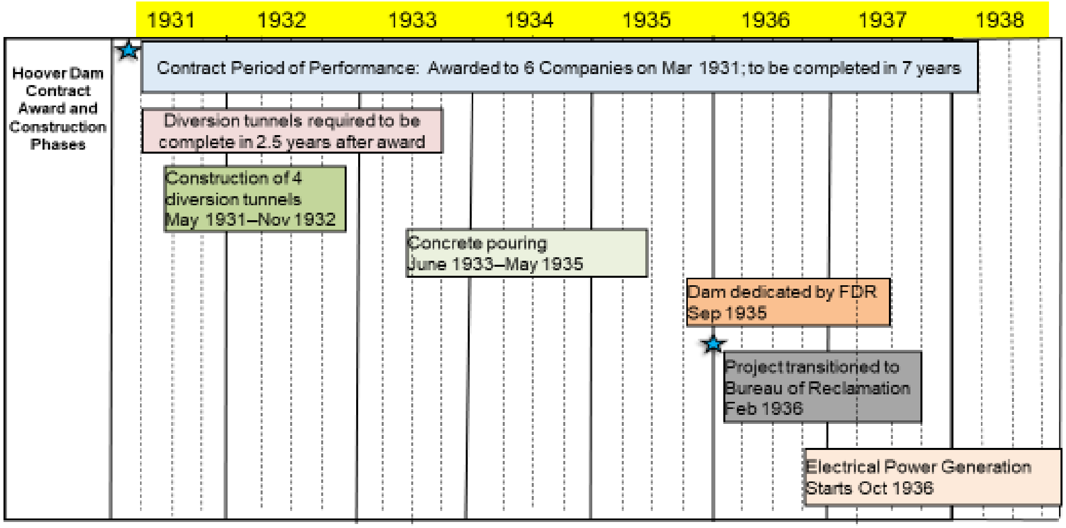


Figure 10. Hoover Dam Schedule (Contract Award and Construction Phases)

Performance: the dam has been successful in all purposes: water storage, flood control, silt control and hydroelectric power, and during construction provided as many as 5,200 jobs during a time when the nation was in financial crisis. In 1955, the American Society of Civil Engineers selected the Hoover Dam as one of the seven modern civil engineering wonders of the United States. (Simonds, 2009, p. 52)

7. PROJECT APOLLO

On July 20, 1969, the Lunar Module Eagle touched down on the surface of the Earth's moon. Astronauts Neil Armstrong and Edwin "Buzz" Aldrin became the first men to touch foot on the moon. The culmination of eight years of near Herculean effort, many recognize this feat as the most remarkable of mankind's achievements. Responding to President John F. Kennedy's challenge to send a man to moon within the decade, the nation reacted swiftly, awarding contracts to major aerospace contractors Boeing's Aerospace Division, Grumman Aircraft Engineering Corporation, and North American Rockwell Corporation Space Division to develop, build, and test the space vehicle. At its height, the Apollo program involved more than 400,000 engineers, scientists, and technicians from more than 20,000 private companies and universities to reach the achievement of man walking on the moon. The costs associated with the program were unprecedented; estimated at $25.4 billion in 1969 dollars or $178.5 billion today. More than the monetary cost, the program took the lives of three astronauts. On January 27 1967, during a "plugs-out" test of the Apollo 1 spacecraft (it was not designated "Apollo 1" until later), while on the launch pad, fire erupted in the Command Module. All three astronauts: Virgil "Gus" Grissom, Edward "Ed" White, and Roger Chaffee died while strapped in their seats. After a critical look at the program and an intensive redesign of the Apollo spacecraft, the program did recover. Initially viewed as the underdogs in the "space race," the United States surpassed the Soviet Union's early achievements with the successful Apollo 11 mission. The Apollo 11 mission was really the culmination of three evolutionary projects (Mercury, Gemini, and Apollo) designed to bridge the technology gaps of space flight and provide NASA confidence.

Figure 11. Apollo 11 Lunar Lander
(https://en.wikipedia.org/wiki/File:Apollo_11_Lunar_Lander_-_5927_NASA.jpg

7.1. Leadership

A program as audacious, expansive, and complex as the Apollo Project encompassed many leaders at multiple levels, with different skill sets, and specific emphases. The massive program covered nearly eight years in time and too many facets for a single individual to lead. This section will discuss three of the myriad leaders that brought Project Apollo to success.

Dr. Werner Von Braun emigrated from Germany and was the core of technical leadership at Huntsville. At the end of WW II, he and 100 members of his rocket development team surrendered to the United States. In the U.S., they assembled and tested captured V-2 rockets for high altitude research. (The Editors of Encyclopaedia. "Wernher von Braun", 2020). Von Braun quickly rose in the ranks and led the development of ballistic missiles for the U.S. Army. In 1957 after the Soviet Union launched two Sputnik satellites in rapid succession, Von Braun led the U.S. effort to launch the nation’s first satellite, Explorer 1, on January 31, 1958. Soon afterwards, he transferred to the newly formed National Aeronautics and Space Administration (NASA) office in Huntsville, Alabama. There he led the development of the Saturn heavy space launch vehicles used in the Apollo program. The performance of these Saturn launch vehicles was unparalleled. Over the history of the Saturn program, there were 32 rocket launches. Each launch was successful and on time and met safe-performance requirements. (The Editors of Encyclopaedia. "Wernher von Braun", 2020)

Beyond his technical accomplishments, Von Braun was also politically and media savvy. As stated by Dick Richardson, CEO of Experience to Lead, about Von Braun, "He could scan the environment beyond his technical expertise to understand the political, societal and economic trends. This ensured his success by anticipating alternative pathways when problems arose." (Richardson, 2019) His leadership skills are evident throughout his career. As WW II progressed into 1944, Von Braun recognized the looming defeat of the Nazi regime. He decided to secure a path for his core engineering team to America. Because of his knowledge of liquid fueled rockets, he knew he would be highly sought after the war ended. Once working in the United States, he rapidly ascended in roles and responsibilities, culminating as the Deputy for Planning at NASA's headquarters in Washington, D.C.

George Low does not have the name recognition with the Apollo Project as Dr. Von Braun, Neil Armstrong, or even Gene Kranz of Apollo 13 fame. However, as time goes on, his reputation grows as one of the premier leaders on the program. As stated by fellow NASA engineer Bob Gilruth during an interview in 1987; "George was good at everything. He was worth about 10 men." (Arrighi, 2019)

During Project Apollo Low oversaw the redesign of the command module spacecraft after the fire in 1967 and the following year he made the decision to accelerate the schedule by sending the first crewed spacecraft around the Moon in December 1968. (Arrighi, 2019)

Perhaps more significant than his leadership during these events was his vision for putting a man on the moon. He was one of the principal advocates for a lunar landing as a goal for NASA in the early days. Despite President Dwight Eisenhower's lack of enthusiasm for a manned flight to the moon, Low persisted. (Jurek, 2018) In early 1961, he led a commission that built a detailed plan for getting to the moon within the decade. (Arrighi, 2019) Fortuitously President John F. Kennedy, just sworn into office, was anxious for a public relations victory on the heels of the Bay of Pigs fiasco. President Kennedy quickly endorsed George Low's moon mission. It was, in fact, his plan that became the foundation for Kennedy's "by the end of the decade" challenge. (Jurek, 2018)

The loss of three astronauts on January 27, 1967 rocked the country and the Apollo program when a fire erupted in the Command Module during testing. George Low generally did not express much emotion even when he did not agree with decisions or facing tough situations. This was not true with the Apollo 1 fire. Low was angry and frustrated that such an event could take place at this point in the program. Fortunately, he was able to effect change as NASA's leadership tapped him to be the program manager of Apollo in April. He was charged with determining what other problems plagued the spacecraft and fix them in time to keep the program on schedule. He recognized one of the causes of the fire was the inadequate coordination of engineering changes on the complex Apollo system. Without a disciplined change management process, the redesign effort would bring more of the same. In response, he established the Configuration Control Board or CCB, providing a formalized system to document and track the hundreds of technical changes generated by the redesign effort. He demanded participation from every branch of the Apollo management and supply chain, including contractors like North American and Grumman. (Jurek, 2018) His efforts paid off.

During the next two years, the CCB met 90 times, considered 1,697 changes and approved 1,341. (Jurek, 2018) The result was restored confidence for the astronauts and within NASA as a whole that Apollo's leadership was doing all it could to build a safe spacecraft to do complete the mission.

During the Apollo redesign effort, George Low recognized and opportunity to make up lost schedule on the program. Apollo 8, scheduled for December 1968, was planned to test the command module, the service module, and the lunar landing vehicle in Earth's orbit. However, the lunar landing vehicle, built by Grumman, was not going to be ready for flight. When it became apparent the lunar landing vehicle would not fly in December, Low proposed a flight to orbit the moon ahead of the landing, with just the command and service modules. Despite opposition by NASA's leadership, the mission was approved just six weeks before the launch of Apollo 8. "It was the boldest decision of the space program," according to Chris Kraft, NASA's head of flight operations. (Jurek, 2018) The move was one of sheer genius, allowing the program to proceed with the systems available. As Low stated, "Navigation to the moon, getting into lunar orbit, the burning of the big engine, the computer programs that were needed for that—we could get all of that out of the way." (Jurek, 2018) Low considered all the resources and capabilities available to contribute to the overarching objective, and then devised and communicated a plan to execute those resources. George Low's adaptability and vision guided America to the moon first and helped ensure the success of Apollo 11's lunar landing in July 1969.

Soon after President John F. Kennedy assumed office in 1961, he asked James E. Webb to consider taking the job of Administrator for NASA. Established in October 1958 the new organization was viewed by many as needing an administrator with a strong technical background. Webb did not have any specific technical expertise, but was an experienced businessman and attorney. (Who is James Webb?, 2020) He had served in the Truman Administration in both budget and State Department positions as well as numerous managerial roles in private industry. He did not see himself possessing the ideal qualifications for the job. However, President Kennedy chose him because of his managerial skills, political acumen, and the ability to navigate the myriad national and international policy issues NASA would face. He was a master at bureaucratic politics, understanding that it was essentially a system of mutual give and take. (Project Apollo: A Retrospective Analysis, 2014)

He led NASA during the height of the Apollo program, with over 35,000 employees in the organization and 400,000 contractors. (Project Apollo: A Retrospective Analysis, 2014). During his tenure, NASA faced some of its darkest days, such as the deadly fire of Apollo 1 and the ensuing effort to get the program back on track. He took much of the blame himself and shield NASA in order to preserve the mission to the moon.

James Webb resigned from NASA in October 1968 before President Lyndon Johnson’s term in office ended. (Project Apollo: A Retrospective Analysis, 2014) He wanted the new president to have a clean slate to select a new administrator. A short nine months later, the Apollo 11 mission successfully landed Neil Armstrong and Edwin “Buzz” Aldrin to the moon’s surface. Webb’s leadership and contribution to the success of Project Apollo was not diminished. John Pike, the Director of the Space Policy Project at the Federation of American Scientists, explained why the American effort was successful stating, "The reason we got to the moon before the Russians was they didn't have anybody to pull it together. The critical difference was we out-managed them." (Redd, 2017) Webb kept NASA on task after the Apollo 1 tragedy, secured funding for the Apollo project, and dealt with the political pressure of Congress throughout his time at NASA.

Although he did not possess the technical genius of Werner Von Braun or George Low, James Webb played an essential role in the extraordinary success of Project Apollo.

Despite the success of Apollo, James Webb was determined to maintain a balance at NASA between science missions and manned space flight. NASA launched over 75 missions into space to study much more than to prepare for the lunar landing. These science missions investigated the stars, the sun, and the Earth, increasing the competence and knowledge of the U.S. scientific community.

The enormously complex program to put a man on the moon required leadership in multiple dimensions, levels, and functional areas. Dr. Von Braun knew rocketry and led the Saturn V development. He also had the uncanny ability to read the political winds and alter course as needed. George Low was “get your hands dirty” engineer who could take on any technical task that arose. Yet, he also was able to conceptualize a mission to the moon and developed a realistic plan to achieve it. James Webb provided the top cover for NASA, delivering Project Apollo with resources, defending the program, and clearing obstacles as needed. All three men were integral to the success of the program through very different roles and contributions.

The leaders discussed in this section are representative of the dozens of leaders that brought Project Apollo to fruition. Unfortunately, it is not possible to recognize the efforts of the leaders associated with literally hundreds of organizations in the U.S. government, industry, universities, and the military supporting the program. As in any large scale or megaproject like Apollo, there are many untold stories of superb leadership that took place.

Rating: Exemplary – It is difficult to recognize the role leadership played in the accomplishments of Project Apollo. The technology challenges notwithstanding, the number of prime contractors, sub-contractors, and overall employees supporting the project was unprecedented in a peace time undertaking. It was a model of collaboration between public and private sectors; multiple government agencies, the U.S. military, universities and thousands of contractors and vendors resulting in a great technological achievement.

7.2. Requirements Definition

The overall mission to fly to the moon, deliver a man safely to its surface, and then return to earth within the decade on its surface appears straightforward. However, the number of derived requirements, those not explicitly stated, needed to achieve this goal was unfathomable. The subsequent section on Technology Usage and Maturity describes some of the technical challenges facing the program driven by the requirements for the moon mission. Breaking the mission into segments is instructive for comprehending the breadth of Apollo's requirements. On July 16, 1969, the Saturn V launch vehicle carried the Apollo spacecraft with three astronauts onboard into space beyond the earth's gravitational pull. During the next phase of the mission, the three major elements of the Apollo spacecraft (Command Module, Service Module, and Lunar Module) were reconfigured and powered by the Saturn IVB burn, started the journey to the moon. Once reaching the moon and entering into lunar orbit, the Lunar Module, with astronauts Neil Armstrong and Buzz Aldrin onboard, separated from the Command Module and descended to the moon's surface. After spending 21.5 hours on the moon's surface, Armstrong and Aldrin departed the moon's surface and rendezvoused with the Command Module. The Command and Service Modules then made the flight back to earth. Once re-established in earth's orbit, the astronauts prepared for re-entry into the atmosphere by jettisoning the Service Module. The Command Module with three astronauts onboard splashed safely into the Pacific after just over eight days of flight. (Apollo 11 Mission Overview, 2019) Each mission segment discussed had unique requirements in multiple arenas such as propulsion, stability and control, communications, navigation, thermal management, and life support. Realistically this list only scratches the surface of the myriad requirements generated by Project Apollo.

Rating: The overall requirement for Project Apollo's mission is well-defined. What is not so evident are the myriad derived and associated requirements needed to achieve the "man to the moon" mission. At the early stages of Project Apollo, NASA was not sure how to reach the moon, thus many requirements were not even in existence. Thus, many requirements were yet to be defined and would be evolving as the project proceeded.

7.3. Technology Usage and Maturity

Project Apollo actually was an evolutionary effort starting with Project Mercury, progressing to Project Gemini, and culminating with the Apollo spacecraft, launched by the Saturn V rocket. Each successive phase proved out technology, gathered scientific data, and gave NASA confidence to forge ahead for the lunar landing mission. Project Mercury focused on placing a man in orbit and provided valuable information on biomedical aspect of space and control and tracking space vehicles. (Project Apollo: A Retrospective Analysis, 2014) Project Gemini was intended to bridge the gap between Mercury and Apollo. The ten manned Gemini missions gave NASA insight on extended operations in space, experience with navigating and docking spacecraft in space, and astronauts operating outside of spacecraft (extra-vehicular activity). Finally, Apollo would provide the vehicle and equipment to reach the moon and support a lunar landing. In conjunction with the manned flight efforts, NASA launched many scientific missions to learn about the moon's environment and surface in preparation for a lunar landing.

What new technologies were developed during this quest for putting a man on the moon? Similar to the discussion of the SR-71 challenges, almost everything about space flight (and specifically manned space flight) would require innovation. Although powered flight had been advancing steadily for nearly sixty years by this time, space flight was a truly new domain.

A comprehensive discussion of the myriad technologies developed for Project Apollo is not realistic for this work. As an alternative, a short discussion of three key representative examples will be briefly described.

The Saturn V rocket that propelled the Apollo spacecraft and astronauts into orbit was an entire technical challenge itself. The rocket stood 363 feet tall and fully fueled weighed 6.2 million pounds. (Rocket Park, 2011).

The rocket's first stage generated 7.5 million pounds of thrust from five massive engines developed for the system. (Project Apollo: A Retrospective Analysis, 2014)

The F-1 engines developed by the Rocketdyne Division (part of North American Aviation) were unprecedented in size and performance. Engineers had to develop new alloys and construction techniques for their successful realization. Even so, one engineer even characterized rocket engine technology as a "black art" without rational principles. (Project Apollo: A Retrospective Analysis, 2014). The massive engine suffered from combustion instability resulting in chaotic forces that would destroy the engine if allowed to go unchecked. Looking back to smaller scale engines including the V-2 rocket of Dr Von Braun's previous work, it was determined the fuel in the F-1 needed to be more evenly distributed prior to combustion. A series of baffles were added to balance the distribution, stabilizing the burn and thus solving the problem.

During the time of Project Apollo, computers were large and could fill a room. Additionally, the normal interface was a card reader that accepted a stack of cards with commands punched on each one. This would not work on Apollo where space and weight were at a premium. Importantly, the astronauts needed direct access to the flight computers carried onboard Apollo.

The onboard computers that flew the command module to the moon and back to earth, and another that flew the lunar module from orbit around the moon to a safe landing, then back up into orbit—were the smallest, fastest, most nimble computers ever created for their era. (Fishman, 2019)

In order to achieve the size required for spaceflight, the Apollo computers used “core rope memory” and was the most efficient available. But, the cost and time required to build each memory unit was high; each unit took eight weeks to build. Factory workers, usually women, painstakingly encoded each bit of information by hand. (Brock, 2017)

The unprecedented size of the Saturn V rockets that would carry the Apollo spacecraft to the moon required new and extraordinary support equipment for maintenance, launch operations, and transport. One such machine was the Crawler-Transporter, designed to move the fully assembled Saturn V and spacecraft “stack” from the vehicle assembly building to the launch pad at Kennedy Space Center.

This is but one of the uniquely designed system in support of Project Apollo and certainly one of the largest. Built by Marion Power Shovel of Ohio, the massive tracked vehicles can carry a payload of 18 million pounds on a platform the size of a baseball diamond with a hydraulic leveling system. The Crawler-Transporter itself weighs 6.6 million pounds and when moving large loads such as the Saturn V rockets, traveled at a speed of 1 mile per hour. (The Crawlers, 2021)

The Crawler-Transporter continued to support subsequent space programs such as the Space Shuttle and does so today transporting commercially operated rockets and payloads to the launch pad.

Figure 12. Crawler-Transporter (https://www.nasa.gov/content/the-crawlers

As previously mentioned, the selected technology challenges described only scratch the surface of the multiple faced in Project Apollo. It was the largest technological non-military endeavor ever undertaken in the history of the United States, and one might argue in modern history. (Project Apollo: A Retrospective Analysis, 2014)

As a final note, the concerted development efforts supporting Project Apollo resulted in dozens of new technology advancements benefiting all of civilization. New fabrics, coatings, medical devices, battery and solar power are but a few of the products that we enjoy today spawned from the Apollo program. It is not unusual for spin-offs to occur because of technical innovative projects, but the sheer number of those from Project Apollo are extraordinary. (Benefits from Apollo: Giant Leaps in Technology, 2004)

Rating: the technology challenges facing Project Apollo were similar to those designing and building the SR-71; many hurdles had to be overcome. There many were “firsts” and “things never been done before” necessary to achieve the goal of safely delivering the astronauts to the moon and back within the decade. Few argue that is still one of the most remarkable and impactful technical human endeavors. As in the words of Neil Armstrong when he stepped onto the surface of the moon on July 20, 1969, “That’s one small step for man, one giant leap for mankind.”

7.4. Vision and Clear Objectives

In the discussion of Vision and Clear Objectives in Section 4.4, President John F. Kennedy’s charge to the nation to put “a man on the moon within the decade” was referenced as the benchmark. His vision for what became Project Apollo is often quoted as the model of brevity, simplicity, ethos and power for a vision statement. (Richardson, 2019) To be clear, although brief and simple, his vision demanded tremendous effort and expenditure of resources to make it a reality. President Kennedy was anxious for the United States to overtake the Soviet Union in the “space race.” The Soviets had been first to launch a satellite into orbit in 1957 and first to put a human in space and orbit the earth. With the Cold War raging, President Kennedy was compelled to demonstrate the nation’s technical prowess and resolve; that it was every bit as capable in space as the Soviet Union. After consultation with NASA’s leadership, he decided a manned flight to the moon would accomplish this goal.

Rating: As mentioned in Section 4.4, President John F. Kennedy’s vision is often used as the model when describing the desirable attributes of a vision statement. The success of Project Apollo bears that out.

7.5. Cost, Schedule & Performance

Cost of Apollo: $25.4 Billion

Schedule: Exceeded the schedule goal by completion within 8 years (the requirement was within the decade)

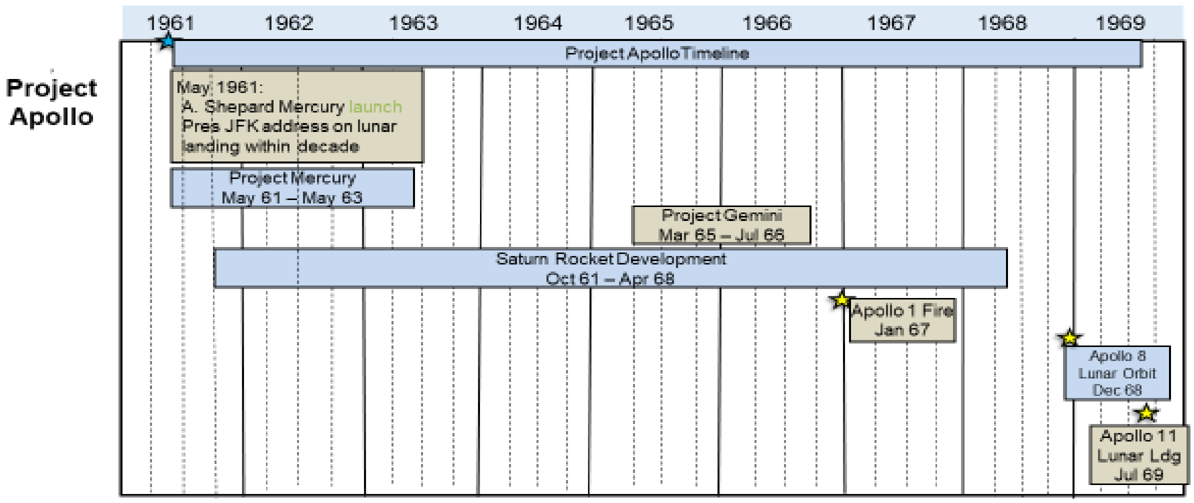


Figure 13. Project Apollo Schedule (JFK challenge to Apollo 11)

Performance: Apollo 11 successfully traveled to the moon and landed two astronauts on the lunar surface. The crew of three returned to earth safely after an eight-day mission. Five subsequent Apollo missions took place successfully landing astronauts on the moon. Apollo 13 did not successfully complete its mission due to an explosion onboard the Service Module. Fortunately, all three astronauts safely returned to earth.

8. CONCLUSIONS

The three projects analyzed in this work were clearly successful in terms of achieving the requirements and meeting the prescribed schedule. As defined in Section 1.4, the project is successful if completed on time and on budget, with all capabilities, features, and functions as initially specified. The question of whether the budget was realized is difficult to ascertain for the SR-71 Blackbird project and Project Apollo due to lack of readily available cost data. The Hoover Dam project was completed at the contractor's original bid. Notwithstanding the lack of budget information on the two aforementioned projects, what are similar aspects that may correlate to their success?

Four key factors were analyzed for each: Leadership, Requirements Definition, Technology Usage and Maturity, and Vision and Clear Objectives. Each project had positive ratings for the factors. Each factor is briefly discussed in context of the three projects analyzed.

8.1. Leadership

Leadership was a key component for all three projects. This is not surprising as success for any endeavor is highly dependent on capable leadership. However, the leaders of the projects provided a blend of skillsets or strengths that made the difference. Clarence "Kelly" Johnson's vast experience in leading innovative aviation projects, his knowledge and expertise of aircraft performance, and his ability to build and motivate high performing teams made him the ideal candidate for the SR-71 Blackbird program. His unique management style encouraged creativity, trust, and accountability persuading many of his employees to turn down promotions within Lockheed to stay on his team. (Rich, 1995) The SR-71 program was perhaps his crown jewel based on the longstanding and number of speed and altitude records it achieved.

Frank “Hurry Up” Crowe also had unique qualifications for his role in managing the construction of the Hoover Dam. Similar to Clarence Kelly Johnson, his career with the Department of Reclamation managing multiple dam construction projects in the western United States prepared him well to lead the Hoover Dam project. As previously described in the leadership section on the Hoover Dam, Crowe was also adept at developing and using technology to achieve project success. He leveraged these construction techniques and tools during the Hoover Dam project. Finally, he was dedicated to the success of the project. As mentioned, he resigned from the Department of Reclamation and hired on with the Morrison-Knudsen Company to play an influential role in the construction. He frequently visited locations around the project at all hours of the day and night, checking on the status of the construction phases. (McBride, 1999)

Due to the complexity, number of stakeholders, and enormity of Project Apollo, many key leaders were involved. This work highlighted three in particular: Dr. Werner Von Braun, George Low, and James Webb. As described in the leadership section of 5.3 Project Apollo, each leader played a specific role in the success of the program. Von Braun brought the corporate knowledge and experience of the V-2 program from Germany and further developed this knowledge working on ballistic missiles for the U.S. Army. This enabled him to lead the Saturn rocket development program, which was vital to the success of Project Apollo. Von Braun also surveilled the political landscape and used his skill to help NASA maintain its stature. George Low was the consummate engineer and problem solver and helped Project Apollo recover from the Apollo 1 tragedy and set back. In addition to his technical prowess, he was a respected leader who cared about the people working for him and particularly those affected by his decisions, in particular the astronauts. Highlighted previously, he was a visionary in laying out a realistic plan to reach the moon. Finally, James Webb served as the NASA Administrator during the time of

Project Apollo, enabling its success by defending the program and securing the necessary funding. As the top official of NASA, he also dealt with the aftermath of Apollo 1 and took much of the blame.

8.2. Requirements Definition

Regarding requirements definition, each of the projects benefited from stable, clear requirements. As previously discussed, this does imply the requirements were small in number or simplistic. For instance the derived requirements for each project was significant, particularly so for Project Apollo. Each major component of the Apollo mission (Saturn V rocket, Command Module, Service, Module, and Lunar Module) had thousands of requirements. However, the overarching requirement (e.g. build an aircraft to fly at speeds greater than Mach 3 and at altitudes in excess of 80,000 feet) for each project remained stable. When requirements frequently change or "creep" when the customer levies new requirements without a commensurate adjustment to budget or schedule, the project is generally at higher risk of not being successful. Overall, the management of the requirements for the SR-71 Blackbird, the Hoover Dam, and Project Apollo was effective and contributed to the overall success of the projects.

8.3. Technology Usage and Maturity

The use of technology in the three projects was significant, although in different aspects. As discussed in Section 4.1, new materials, propulsion, life support systems, and manufacturing methods all required development for the SR-71 Blackbird to be successful. The Lockheed Skunk Works team matured these technologies to enable extended operation of the aircraft at speeds and altitudes never achieved before. Although similar in some technical respects, Project Apollo was perhaps an order of magnitude greater in the technology challenge than the SR-71 program faced. The mission to land on the moon and return the astronauts safely to earth required significantly more resources in time and money to achieve success. From concept studies to first flight of the A-12 (predecessor to SR-71 aircraft) was four years. President Kennedy announced the goal of reaching the moon in May 1961 and the Apollo 11 mission took place just over eight years later in July 1969. Comparing the resources for the two projects is illustrative as well; approximately 300 vendors and subcontractors supported Lockheed in developing the SR-71 aircraft. At its peak, over 400,000 people and 20,000 vendors and subcontractors worked on Project Apollo. There were multiple new technologies used in Project Apollo, some were matured in evolutionary steps as part of the Mercury, Gemini, and Apollo projects. Manned space flight had been just demonstrated when NASA embarked on the mission to land on the moon.

The Hoover Dam project did not require new technologies to be successful. However, as discussed in Section 4.2, the challenge it presented was the scale of the project in terms of size, amount of concrete required, and the lack of infrastructure to support the effort. New technologies were used in the construction of the dam such as the cooling system to deal with the heat load from the concrete curing process as well as the overhead cable system to transport materials rapidly on the dam site. These advances in construction technology had been demonstrated in earlier dam construction projects so they were proven out. In terms of the NASA technology readiness levels, these technologies could be ranked as TRL 9, whereby the system has been completed and demonstrated in the actual environment.

In summary, the technology usage and maturity for the SR-71 aircraft and Project Apollo were critical factors involved in their success. Any technology not at the appropriate maturity level would delay the schedule or jeopardize the overall success of the project. Despite the high risk technologies used on these two projects, the combination of the other factors (strong leadership, well-managed, stable requirements, and clear objectives) drove their success. The Hoover Dam did not rely on technology usage for the dam itself, but did so in the construction methods utilized.

8.4. Vision and Clear Objectives

As stated in Section 3.4, the vision and objective of each project was to be evaluated through the consideration of clarity, ambitiousness, and realism. There is ample documentation on the vision for Project Apollo as laid out by President John F. Kennedy. Indeed, his vision is often the benchmark for assessing vision statements. It was clear, ambitious almost to the point of being audacious, and realistic. One could argue whether the requirement for a lunar landing within the decade was realistic, but in retrospect, it proved to be so. There is less evidence or at least publically available information on the actual vision and objectives related to the SR-71 project. Discussed in Section 4.1, the need for such an aircraft was compelling in light of the ongoing Cold War and the needs of the leadership of the United States in monitoring our adversaries. The vital and more challenging requirement for the ability to conduct reconnaissance with impunity was a major factor in the vision of the A-12 and SR-71 aircraft. The challenges of the technologies facing the developers made it an ambitious undertaking.

The vision for a dam on Colorado River basin had been emerging for many years prior to the actual Hoover Dam project. First as a source of water for irrigation for southern California, then for flood control as the devastation of flooding in the early 20th century occurred, and finally as a source of hydroelectric power, the vision evolved. Because of the political nature the undertaking, the multiple states affected, and many commercial interests at stake, it was nearly 80 years before the vision became a reality. The vision for what became the Hoover Dam was ambitious in that it was the largest dam ever built in the United States at the time and with no nearby infrastructure to support the construction. Another aspect of the ambitious nature of the project is that multiple companies had to merge together to be able afford the performance bond, indicative of the large scale the endeavor.

8.5. Unique Aspects of the Projects

The SR-71 aircraft development, the construction of the Hoover Dam, and Project Apollo were successful. However, it is of interest to identify and discuss other considerations and circumstance that influenced each project. Although difficult to quantify or determine precisely, each project enjoyed or benefited from unique conditions and environments.

Cold War Environment

The existential threat of the Cold War helped garner support for both the SR-71 aircraft and Project Apollo. The SR-71 was in fact a product of the need (perceived or real) for rapid reconnaissance and related intelligence gathering of the Soviet Union and its allies. Project Apollo was also viewed as critical to demonstrate the United States' leadership in the "space race" with the Soviet Union. As quoted from a NASA report, "The Cold War realities of the time, therefore, served as the primary vehicle for an expansion of NASA's activities and for the definition of Project Apollo as the premier civil space effort of the nation." (Project Apollo: A Retrospective Analysis, 2014) This ensured support from a broad array of high-level stakeholders including the White House, Congress, and the Department of Defense. Specifically for the SR-71 (and its predecessor the A-12), the Central Intelligence Agency and the United States Air Force were also strong advocates. This high-level support translated into sufficient funding for the projects from Congress. Another potentially enabling factor for Project Apollo was the pride and patriotic fever for the United States to be first to the moon. President Kennedy recognized the seriousness of the Soviet Union's challenge for dominance in space and his subsequent vision for the United States lunar mission was a response to that challenge. NASA, the thousands of contractors supporting Apollo, and the general populace were onboard with the nation's quest to be first to the moon as well. In fact, the Grumman Corporation assigned its best and brightest to the Lunar Module program, without long-term business expectations. It only produced 15 vehicles with a net profit of only 1.9% at the contract's peak in 1969. (Skurla, 2004)

Security classification

Another aspect of the A-12/SR-71 program that may have been helpful to its success was the level of security classification applied to the program. Often labeled as a "Black" program, the secrecy surrounding may shield it from the scrutiny other programs would normally receive. Indeed, this may be true of any "Black" project; however, this may not always provide benefit. Again, it is difficult to determine how the secrecy of the SR-71 project contributed to its success. However, it may be fair to say that limited visibility and minimal reporting simplified the team's processes, allowing it to focus on the development of the aircraft.

Lax enforcement of state laws

In the case of the Hoover Dam, the construction efforts benefited from lax enforcement of state laws. Mentioned briefly in Section 4.2, the Six Companies were responsible for digging four tunnels to divert the Colorado River in order for the dam construction to take place. The four tunnels, two in the Nevada canyon wall and two in the Arizona canyon wall, were approximately one mile in length and 50 feet in diameter. The tunnels had to be completed within 2 ½ years of contract award to allow time for the dam construction within the overall seven year contract period. In other words, the diversion tunnels were on the critical path. Six Companies used trucks powered by internal combustion engines to transport the rock debris and material excavated from the tunnels. However, Nevada law prohibited the use of equipment powered by internal combustion engines in confined spaces, such as tunnels. Despite Nevada’s protest and lawsuit against Six Companies, the court ruled against Nevada. Six Companies exploited the lack of enforcement of the law and completed the tunnel projects one year ahead of schedule. Whether or not the overall dam project could have been completed within the seven-year period without the use of trucks for the tunnel excavation is unknown. Nevertheless, the fact that Nevada’s law was not enforced, allowed Six Companies to accelerate the excavation process perhaps at the expense of the workers in the tunnels.

Innovative Management Techniques

One final aspect for discussion with respect to these three projects is the innovative management techniques or relationships employed. Each project adopted a new management framework, by design or necessity. The SR-71 project team led by Lockheed’s Clarence Kelly Johnson worked closely with Pratt and Whitney. This relationship was touched on briefly in Section 4.1 with a quote from William Brown regarding the collaboration and teamwork he saw while serving as the Engineering Manager at Pratt and Whitney. This collaborative environment was essential for the overall success of the program as the two contractors operated as one team, enhancing communication and sharing of information. The integration of the J-58 engine into the aircraft was an enormous challenge, thus the one team philosophy was fundamental to its success. Noted in Section 4.1 as well, the government’s “hand’s off” approach in providing oversight to the Lockheed and Pratt and Whitney team allowed freedom to make changes with minimal administrative burden, saving time and money.

When construction started on the Hoover Dam, it would be the largest dam ever built in the United States. Discussed in Section 4.2, no single company had obtained the financial backing to obtain the performance bond for the project. Thus, the Six Companies Consortium arose to join forces for the construction of the dam. Aside from the increased financial clout the merger offered, each company possessed different expertise, collective knowledge, and construction experience that contributed to the Hoover Dam. Although not unique today, the Six Companies working together on the Hoover Dam was a relatively new concept for construction projects. The construction of the dam required multiple construction projects (summarized in Section 4.2) and the companies making up the consortium leveraged their respective skillsets to build the myriad infrastructure projects in addition to the dam and the directly related facilities. The Six Companies did not take on any further joint ventures after the Hoover Dam, but went their separate ways. (Hoover Dam: A Project for the Ages, 2020)

Project Apollo is most notable for the technical achievement of reaching the moon, landing two men on the moon surface, and returning to earth safely. Many technological and engineering achievements enabled Project Apollo to be successful. Section 4.3 mentioned just a few of the many technology spinoffs resulting from Project Apollo. However, achievement in the management field was also remarkable. As stated by Dale Wolfe in Science, "…It may turn out that [the space program's] most valuable spin-off of all will be human rather than technological: better knowledge of how to plan, coordinate, and monitor the multitudinous and varied activities of the organizations required to accomplish great social undertakings." Indeed, orchestrating the efforts of the thousands of contractors and sub-contractors producing the components of the Apollo spacecraft was a triumph of the project. For example, the Saturn rocket development involved five major contractors with more than 250 subcontractors, provided millions of parts and components for use in the launch vehicle, all meeting exacting specifications for performance and reliability. (Project Apollo: A Retrospective Analysis, 2014) Noted previously in Section 4.3, all 32 launches in the development and operation of Saturn V rockets were successful.

Another management challenge for the program was overcoming the biases and cultural differences of the various communities involved. This included NASA civil servants, contractors, and university personnel, all who had different priorities and expectations. Yet, even stronger differences existed between the engineering community and the scientific community within Project Apollo. The engineers were tasked to build the hardware and software to accomplish the mission within budget and to meet schedule. Scientists on the other hand were concerned about designing experiments to continue research in space and bristled at the constraints imposed by the engineers. (Project Apollo: A Retrospective Analysis, 2014) Maintaining the balance to satisfy each side while accomplishing the overall objective laid out by President Kennedy was a constant struggle for NASA's leadership. One final aspect of the management of Project Apollo was the paradigm shift that took place regarding the amount of in-house work conducted by NASA. Because of the enormity of the project, NASA did not have the personnel or resources to develop and build the spacecraft and supporting systems. The work was accomplished by contractors with NASA personnel providing oversight and technical direction. NASA's engineers struggled with how best to accomplish this oversight and often sparred with leadership. During development of the Saturn rocket, the second stage was delivered to the Marshall Space Center in Huntsville, Alabama. After testing identified some anomalies, NASA personnel started a time-consuming engineering investigation jeopardizing the schedule. James Webb informed Werner von Braun to cease the practice and to trust the industry partners. (Project Apollo: A Retrospective Analysis, 2014) Eventually a compromise was negotiated; called the 10 percent rule, whereby 10 percent of NASA's funding was spent to ensure in-house expertise was available while also confirming the contractors met their performance specifications. (Project Apollo: A Retrospective Analysis, 2014)

9. WRAP UP THOUGHTS

In summary, the SR-71 Blackbird project, the Hoover Dam, and Project Apollo all deemed successful projects. Superior leadership, well-defined requirements, and clear objectives were common to all three. The technologies used on the SR-71 and Project Apollo were successfully achieved for both, but required a concerted maturity effort by the developing teams. The Hoover Dam employed technology advances during construction ensuring the construction was completed within budget and on schedule. Other factors came into play that contributed to the success of the each project.

Author and scholar Victor Davis Hansen observed, “Our ancestors were builders and pioneers and mostly fearless” in an article he penned about the accomplishments of past generations (Hansen, 2019). The author feels similarly about the visionaries, leaders, and teams that led the three projects discussed and hopes they will be emulated in the future.

10. REFERENCES

Apollo 11 Mission Overview. (2019, May 15). Retrieved from NASA.gov: https://www.nasa.gov/mission_pages/apollo/missions/apollo11.html

Arrighi, R. S. (2019, December 19). *George Low Spurred Moon Landings.* Retrieved from NASA.gov: https://www.nasa.gov/feature/glenn/2019/george-low-spurred-moon-landings

Benefits from Apollo: Giant Leaps in Technology. (2004, July). Retrieved from NASA.gov: http://sti..nasa.gov/tto/spinoff.html

Bennie J. Davis, I. (2017, July 10). Airframe: The SR-71 Blackbird. *Airman Magazine*.

Brock, D. C. (2017, September 29). *Software as Hardware: Apollo's Rope Memory.* Retrieved from Spectrum IEEE: https://spectrum.ieee.org/tech-history/space-age/software-as-hardware-apollos-rope-memory

Brown, W. (1981). J-58/SR-71 Propulsion Integration or the Great Adventure into the Technical Unknown. *Conference Proceedings American Institute of Aeronautics and Astronautics* (p. 5). Long Beach, CA: American Institute of Aeronautics and Astronautics.

Chief Engineer: Frank Crowe. (1999, January 18). Retrieved from American Experience: https://www.pbs.org/wgbh/americanexperience/features/hoover-crowe/

Fishman, C. (2019, July 17). *The Amazing Handmade Tech That Powered Apollo 11's Moon Voyage.* Retrieved from History: https://www.history.com/news/moon-landing-technology-inventions-computers-heat-shield-rovers

Flyvbjerg, B. (2014, October). What You Should Know about Megaprojects and Why:. *From Academia: Summaries of New Research for the Reflective Practitioner*, pp. 1-4.

Hansen, V. D. (2019, October 10). *Members of Previous Generations Now Seem Like Giants.* Retrieved from Jewish World Review: http://www.jewishworldreview.com/1019/hanson101019.php3

Haughey, D. (2010, January 2). *A Brief History of Project Management.* Retrieved from ProjectSmarts: https://www.projectsmart.co.uk/brief-history-of-project-management.php

Hoover Dam: A Project for the Ages. (2020, July 27). Retrieved from Bechtel Corporation : https://www.bechtel.com/projects/hoover-dam/ `

Johnson, C. L. (1981). *Development of the SR-71 Blackbird.* Palmdale, CA: Lockheed Corporation.

Jurek, R. (2018, December). *The Man Who Won the Moon Race.* Retrieved from Air and Space Magazine: https://www.airspacemag.com/space/apollo-8-george-low-profile-180970807/

Kennan, G. (1917). *The Salton Sea An Account of Harriman's Fight with the Colorado River.* New York, NY: The MacMillan Company.

Kennedy, J. F. (1961). *Urgent National Needs* . Washington, D.C.: NASA Historical Reference Collection, NASA History Office.

Kennedy, S. (2021, March 26). *The F-35 May Be Unsalvageable*. Retrieved from The Hill: https://www.msn.com/en-us/news/politics/the-f-35-may-be-unsalvageable/ar-BB1eZTYE?li=BBnb7Kz

McBride, D. (1999, February 7). Frank Crowe. *The Las Vegas Review-Journal*, p. 1.

Nelson, J. (2004). *Reign of Iron.* New York, NY: HarperCollins.

Office of the Director, Defense Research and Engineering. (2009). *Department of Defense Technology Readiness Assessment Deskbook.* Arlington, VA: Department of Defense.

(2021). *Operation Warp Speed.* Washington, D.C.: United States Government Accountability Office .

(2014). *Project Apollo: A Retrospective Analysis.* Washington, D.C.: National Aeronautics and Space Administration .

Project Management Institute. (2004). *A Guide to the Project Management Body of Knowledge (PMBOK Guide).* Newtowne Square, PA: Project Management Institute, Inc.

Redd, N. T. (2017, November 17). *James Webb: Early NASA Visionary*. Retrieved from Space.com: https://www.space.com/38870-james-webb-biography.html

(1991). *Report on the Review of the A-12 Aircraft Program (Report #91-059).* Arlington, VA: Inspector General, Department of Defense.

Requirements Development. (2018, June 14). Retrieved from AcqNotes Understanding Aerospace Program Management: https://acqnotes.com/acqnote/tasks/derived-requirements

Rich, B. R. (1995). *Clarence Leonard (Kelly) Johnson:L A Biographical Memoir.* Washington, D.C.: National Academies Press.

Richardson, D. (2019). *Apollo Leadership Lessons: Powerful Business Insights for Executives.* Gold River, CA: Authority Publishing.

Rocket Park. (2011, September 16). Retrieved from NASA.gov: https://www.nasa.gov/centers/johnson/rocketpark/saturn_v.html#:~:text=The%20Saturn%20V%20rocket%20was,weight%20of%20about%20400%20elephants

Santucci, J. (2013). *The Lens of Power: Aerial Reconnaissance and Diplomacy in the Airpower Century.* Maxwell Air Force Base, AL: Air University.

Scott Wolfe, J. (2013, January 21). Types of Construction Projects – What are They and Why You Should Care. *www.levelset.com/blog*, p. 1.

Shulkin, D. D. (2021, January 21). *What Health Care Can Learn from Operation Warp Speed.* Retrieved from NEJM Group Public Health Emergency Collection: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7819632/

Simonds, W. J. (2009). *Hoover Dam: The Boulder Canyon Project* . Denver, CO: The Bureau of Reclamation.

Skurla, G. M. (2004). *Inside the Ironworks: How Grumman's Glory Days Faded* . Annapolis, MD: Naval Institute Press .

Smith, C. C. (2008). *Superpath: A Non-computerized Probablistic Scheduling Methodology Using First Principles of the U.S. Navy's Program Evaluation Review Technique.* College Park, MD: Graduate School of the University of Maryland.

The Crawlers. (2021, March 23). Retrieved from NASA.gov : https://www.nasa.gov/content/the-crawlers

The Editors of Encyclopaedia. "Wernher von Braun". (2020, June 12). Retrieved from Encyclopedia Britannica: https://www.britannica.com/biography/Wernher-von-Braun/

The Importance of Concrete Temperature Gradients. (2020, June 4). Retrieved from Giatechnical: https://www.giatecscientific.com/education/the-importance-of-concrete-temperature-gradients/

The Mitre Corporation. (n.d.). Assessing Technical Maturity. *Mitre Organization Publications Systems Engineering Guide*.

The Standish Group. (1995). *The Standish Group Report Chaos.* The Standish Group International, Inc.

U-2 Overflights and the Capture of Francis Gary Powers, 1960. (2020, June 25). Retrieved from Office of the Historian United States Department of State: https://history.state.gov/milestones/1953-1960/u2-incident

United States Senate Permanent Committee on Investigations Committee on Homeland Security and Governmental Affairs . (2014). *THE AIR FORCE'S EXPEDITIONARY Combat Support System (ECSS): A Cautionary Tale on the Need for Business Process Re-engineering and Complying with Acquisition Best Practices.* Washington, D.C.: Permanent Subcommitte on Investigations.

Who is James Webb? (2020, 12 1). Retrieved from James Webb Space Telescope Goddard Space Flight Center : https://www.jwst.nasa.gov/content/about/faqs/whoIsJamesWebb.html