

DISSERTATION

SYSTEM DYNAMICS MODELING AND HUMAN FACTORS ANALYSIS OPTIMIZATION
OF GOVERNMENT AIRCRAFT OPERATIONS

Submitted by

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ABSTRACT

SYSTEM DYNAMICS MODELING AND HUMAN FACTORS ANALYSIS OPTIMIZATION OF GOVERNMENT AIRCRAFT OPERATIONS

Aircraft operations, whether commercial, governmental, or private, require a careful balance among maintenance, training, safety, and resource allocation. These domains are highly interdependent; inadequate allocation in one area degrades performance in others, while improvements in one domain can enhance overall system effectiveness. System dynamics modeling provides a framework for simulating internal organizational processes and evaluating outcomes across both predictable and uncertain scenarios. A tailored system dynamics model enables decision-makers to assess the impact of key variables, such as customer cost, employee compensation, and staffing levels, on overall system performance in near-real-time. Government aircraft operations operate under strict budgetary constraints, funding allocation rules, and varying expiration timelines for appropriated funds. Optimizing these constraints can redirect resources toward safety-enhancing initiatives, thereby reducing risk, lowering costs, and improving operational efficiency. The Human Factors Analysis and Classification System (HFACS) can be used to further support this effort by identifying areas where targeted resource investments yield the greatest safety benefits.

This research identifies a critical capability gap in process optimization within government aircraft operations. To address this gap, an integrated system dynamics model is developed to guide decision-makers in increasing value, forecasting outcomes in non-standard scenarios, and enhancing the application of HFACS to strengthen organizational safety

programs. Impact nano-codes is determined to be an important factor in targeting areas to concentrate.

Several significant contributions emerged from this research. First, a mathematical framework was established to quantify organizational value at an unprecedented level of detail for government aviation operations. The framework is sufficiently adaptable for application to analogous systems, including commercial corporations, small businesses, households, and individual financial or operational models. Second, a comprehensive system dynamics model of a government aviation organization was developed, representing a capability not previously identified in existing literature. Furthermore, the research demonstrated that optimization of government aviation operations can directly enhance safety initiatives through more effective allocation of mitigation resources. A novel advancement of this work was the integration of quantitative impact values into human factor nano-codes within the NASA Human Factors Analysis and Classification System (NASAHFACS) process. This enhancement provides a quantitative methodology for prioritizing resource allocation, mishap mitigation, and operational risk-reduction strategies.

The methodologies proposed in this dissertation are intended to be adaptable and scalable for implementation across a broad range of flight operations organizations. Future organizations may tailor and refine these methodologies to support the development of management policies focused on operational optimization, resource efficiency, and safety enhancement. Collectively, these processes provide a foundation for improving organizational effectiveness, operational resilience, and long-term mission success.

ACKNOWLEDGEMENTS

There are many individuals throughout my life who have influenced my pursuit of higher education and served as enduring role models. My mother, who recently retired after 50 years as a junior high and high school teacher, fostered an environment in which education was a central priority. She has been, and continues to be, a defining influence in my life. My father, a skilled welder, taught me the value of designing and building through creativity and hands-on effort. The combination of my mother's passion for learning and my father's ingenuity established the foundation for who I would ultimately become, an engineer.

I would also like to express my deep gratitude to my children for their patience and support throughout the many years I dedicated to academia and government service. There were countless occasions when I had to postpone vacations, family time, and even simple evenings at home due to professional and academic responsibilities. Their understanding and sacrifice mean more to me than they may ever fully realize.

I enlisted in the United States Marine Corps with the goal of earning a college education, serving my country, and seeing the world. Through that experience, I achieved all of this and much more. The Marines and fellow service members with whom I served are truly exceptional. Their camaraderie, loyalty, and profound sense of responsibility shaped me in lasting ways. Their commitment to one another and to mission success made them some of the most impactful mentors in my life.

I would like to acknowledge my colleagues at NASA's Johnson Space Center and Headquarters for their invaluable support in ensuring that the processes I developed were both

realistic and accurate. Although I have since retired, they have continued to support me in this endeavor, for which I am sincerely grateful.

I would also like to thank my friend and CPA, Jon Hurt, for generously sharing his time and expertise. His guidance in explaining how businesses are valued, including key inputs and outputs of value, provided critical insight that informed the development of the system dynamics model underlying this dissertation.

To my professors, I am sincerely grateful for your dedication to fostering my intellectual growth and encouraging me to exceed my own expectations. I extend my highest appreciation to my advisor, Dr. Ronald Sega, whose steadfast support and commitment were instrumental throughout this journey. His willingness to remain engaged through the completion of my dissertation reflects a level of mentorship for which I am deeply thankful. It was also an honor to have him present, like family, when I received the Neil Armstrong™ Award of Excellence. During some of the most challenging periods, his guidance, delivered with both rigor and encouragement, helped carry me to the finish line.

To my co-advisor, Dr. Thomas Bradley, thank you for your continued support, guidance, and patience throughout the completion of my academic program. I would also like to express my sincere appreciation to my committee members, Dr. Mike Borky and Dr. Bret Windom, for their invaluable feedback and participation throughout my dissertation and dissertation defense. I am truly grateful for their time, expertise, and unwavering commitment to this endeavor. I am also honored to have had Dr. Donald Pettit serve on my dissertation committee. Thank you for your ongoing support and understanding as timelines evolved over the years.

AUTOBIOGRAPHY

Trent C. Kingery served 24 years in the United States Marine Corps as an F/A-18 pilot, lead flight instructor, avionics technician, and acquisition specialist. His military career included multiple deployments in support of Operation Iraqi Freedom and Operation Enduring Freedom. During this time, he earned nine Strike/Flight Air Medals, accumulated 695 combat flight hours, flew 175 combat missions and completed 165 carrier landings. Following his retirement from military service in 2014, Mr. Kingery transitioned to government aerospace as a Senior Aerospace Engineer for the United States Army in Corpus Christi, Texas.

In 2017, Mr. Kingery joined NASA as a Maintenance Manager and Research Pilot at Wallops Island, Virginia, before transferring to the Flight Operations Directorate at NASA Johnson Space Center in Houston, Texas. During his tenure at NASA, he held multiple leadership roles, most notably serving as a Supervisory Research Pilot and Chief of Aviation Safety. In these positions, he instructed astronauts in the T-38N jet trainer and conducted airborne science missions worldwide in Gulfstream business jets. He was recognized with the prestigious “YES, IF” Safety Award for excellence in implementing a robust Human Factors Analysis and Classification System (HFACS) and continues to support instruction in the NASAHFACS certification program.

Following his retirement from NASA in February 2025, Mr. Kingery joined United Airlines as a Boeing 737 pilot and currently serves in the airline’s Chief Pilot Office at George Bush Intercontinental Airport in Houston, Texas. He currently serves on the Board of Trustees of the Astronaut Scholarship Foundation and is a Ph.D. candidate in Systems Engineering from Colorado State University.

POSITIONALITY STATEMENT

The views and opinions expressed in this dissertation, including any specific case studies or scenarios, are solely those of the author and do not reflect the official policies, positions, or endorsements of the National Aeronautics and Space Administration (NASA), the U.S. Department of War (DoW), or any other affiliated organization.

All monetary values utilized within the system dynamics model are approximated financial data. Notwithstanding these approximations, the data contained herein remains suitable for conducting valid trend analyses and supporting scenario-based optimization. The underlying data supporting this research, whether financial or technical, may be provided by NASA upon request, as applicable, in accordance with the provisions of the Freedom of Information Act (FOIA).

This dissertation, including the system dynamics model presented herein, has undergone review through Delphi committee processes, has been compared to actual financial data, and has been presented to both NASA program management and Johnson Space Center legal counsel.

DEDICATION

This dissertation is dedicated to my family, especially my children, grandsons, and granddaughter: Zane, Brianna, Brennen, Logan, Jace, Sullivan, and Wren. Your love, encouragement, and unwavering support have been a constant source of strength throughout my professional, academic, and personal journey. You have inspired me to strive for excellence in my career, pursue higher education with determination, and be the best father and grandfather possible. Every challenge and sacrifice made along the way was motivated by my desire to create a better future for our family. Without your patience, understanding, and support over the years, this achievement may not have been possible. I am deeply grateful for each of you and love you all dearly.

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CHAPTER 1: INTRODUCTION

1.1 Content of Dissertation

This dissertation has been developed over several years and has evolved in response to changes in operational processes, organizational assets, and external socioeconomic conditions. The most significant of these changes occurred in 2020, when the COVID-19 pandemic affected organizations worldwide. As a result, the system dynamics model, which constitutes the primary analytical effort of this dissertation, was expanded to incorporate pandemic-like effects using real-world data. During the latter stages of this research, it became evident that human factors analysis and optimization could be integrated with system dynamics optimization to support the development and implementation of safety mitigation strategies. The overarching objective of this dissertation is to help transition decision-making from reactive practices to deliberate, efficient, proactive processes that enhance safety outcomes.

Chapter 1 establishes the need to improve government aircraft operations through the application of systems engineering principles. To accomplish this, current government aircraft operations must first be analyzed. Because of the availability of performance metrics and the opportunity to benefit an actual organization, the flight operations of the National Aeronautics and Space Administration (NASA) at Johnson Space Center (JSC) was selected as the focus of this study. To accurately represent NASA aircraft operations at JSC, actual assets, missions, and aircraft capabilities were incorporated as both fixed and variable model entities. A thorough understanding of the financial and functional structures of aircraft operations is necessary to properly construct the baseline system dynamics model. The next step involved identifying the hierarchical metric structure required to optimize the model. Ultimately, metrics and their

interdependencies must be clearly defined and organized so the model can function properly. The research presented in Chapters 1 through 4 also serves, in part, as the literature review supporting the topics addressed in those chapters.

Chapter 2 focuses on the development of the baseline system dynamics model representing organizational value. This baseline enables comparison to historical trends and incorporates the results of three Delphi committees conducted at different stages of model maturity to validate the realism and functionality of the model. This chapter is dedicated to the structure and validation of the baseline system dynamics model. Once validated as acceptably usable and verified to be sufficiently accurate, the baseline model can replicate current flight operations at JSC and serve as the foundation for optimization.

Chapter 3 expands the baseline model by incorporating additional functionalities to simulate significant scenarios that the organization may experience. This chapter addresses the modeling of major events using the validated baseline model from Chapter 2 and the optimization of key variables under changing conditions. One of the major enhancements is the inclusion of a pandemic trigger that allows the user to define the start date and duration of a pandemic event within the model time horizon. Because actual pandemic effects were observed beginning in 2020, real-world data acted as reference modes to validate this additional functionality. Program managers were consulted to ensure the accuracy of the data used in the model. This chapter also incorporates other real-world scenarios, such as fuel cost increases and budget cuts, and evaluates how dependent variables may be optimized to compensate for such changes.

Chapter 4 was developed late in the research process to bridge aircraft operations optimization and safety. With additional resources generated through optimization, targeted

safety strategies can be implemented to reduce the recurrence of mishaps and close calls. This chapter discusses the NASA Human Factors Analysis and Classification System (NASAHFACS), along with additional recommended measures to further prevent mishap and close call events. These measures are intended to improve both organizational safety and operational effectiveness.

Chapter 5 presents a summary of the dissertation and its principal contributions. This includes a synthesis of the importance of model application, scenario results, safety strategies, and recommendations for future work. To facilitate the requirements scope of future work, a final Delphi Committee was conducted to review the current system dynamics model and to brainstorm capabilities that would further assist NASA decision-makers in future versions.

1.2 Systems Engineering Applications

Systems engineering, particularly through the use of system dynamics, is a powerful methodology that can be applied to a wide range of systems, including business operations, engineered designs, and life-cycle processes [1]. System dynamics generally assumes rational decision-making [2]. However, when supported by historical data and carefully designed surveys, decision behavior can be reasonably approximated and modeled. Establishing the architecture of aircraft operations before constructing the baseline model is essential for efficient and accurate model development [1] [3] [4]. This requires a detailed understanding of how funds are generated, how they are allocated throughout the organization, and how they are ultimately expended [2] [5].

The systems engineering methodology used in this dissertation begins with defining the need or objective [4] [6] [7]. The steps used in this research include historical analysis,

architectural development, metric acquisition, top-down model design, baseline model verification and validation, application of scenario-based analyses to a validated model, and publication of the results. Each step can be time-consuming; however, the fidelity of the model and the legitimacy of the results depend heavily on the model structure, input metrics, and assumptions. Assumptions are also necessary to simplify the model, make it manageable, and facilitate modification [8]; these are listed in *Appendix A*. Sensitivity analysis can further identify key organizational elements that may not have been previously recognized. Chen et al., for example, performed a similar sensitivity analysis when comparing aircraft leasing options [6].

1.2.1 Systems Engineering Defined

Systems engineering is a specialized discipline that considers the holistic view of a system [9]. Systems may be physiological, technical, abstract, inert, or a combination thereof. Several authoritative definitions of systems engineering are provided below:

“An interdisciplinary approach and means to enable the realization of successful systems” [10].

“Systems Engineering is a holistic approach to creating and managing the world’s most complex projects. It’s the method used to ensure that all the separate components of a complex system, whether it’s a modern jet, a smart city, or a global logistics network, work together successfully to achieve a common goal. Instead of just focusing on one part, Systems Engineering uses a big-picture mindset to oversee the entire life cycle of a project, from the initial idea all the way through development, operation, and retirement. For a more formal definition: Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods” [9].

“The application of scientific and engineering efforts to (a) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; and (c) integrate reliability, maintainability, safety, survivability, human engineering, and other such factors into the total engineering effort to meet cost, schedule, supportability, and technical performance objectives” [11].

“An interdisciplinary collaborative approach to derive, evolve, and verify a life-cycle balanced system solution which satisfies customer expectations and meets public acceptability” [12].

“An approach to translate operational needs and requirements into operationally suitable blocks of systems. The approach shall consist of a top-down, iterative process of requirements analysis, functional analysis, and allocation, design synthesis and verification, and system analysis and control. Systems engineering shall permeate design, manufacturing, test and evaluation, and support of the product. Systems engineering principles shall influence the balance between performance, risk, cost, and schedule” [10].

Depending on the type of system under consideration, one or more of these definitions may apply. In the context of this dissertation, creating a system dynamics model of NASA aircraft operations supports optimization of the total system through flexible modeling and provides management with information to support decision-making [13] [14].

1.2.2 NASA's Systems Engineering

NASA Procedural Requirements (NPR) 7123.1B, NASA Systems Engineering Processes and Requirements, defines systems engineering as follows: “Systems Engineering (SE) is a

logical systems approach performed by multidisciplinary teams to engineer and integrate NASA's systems to ensure NASA products meet customers' needs. Implementation of this systems approach will enhance NASA's core engineering capabilities while improving safety, mission success, and affordability” [15, p. 5]. NASA’s common Systems Engineering framework consists of three primary elements: common technical processes, workforce, and tools and methods (Figure 1).

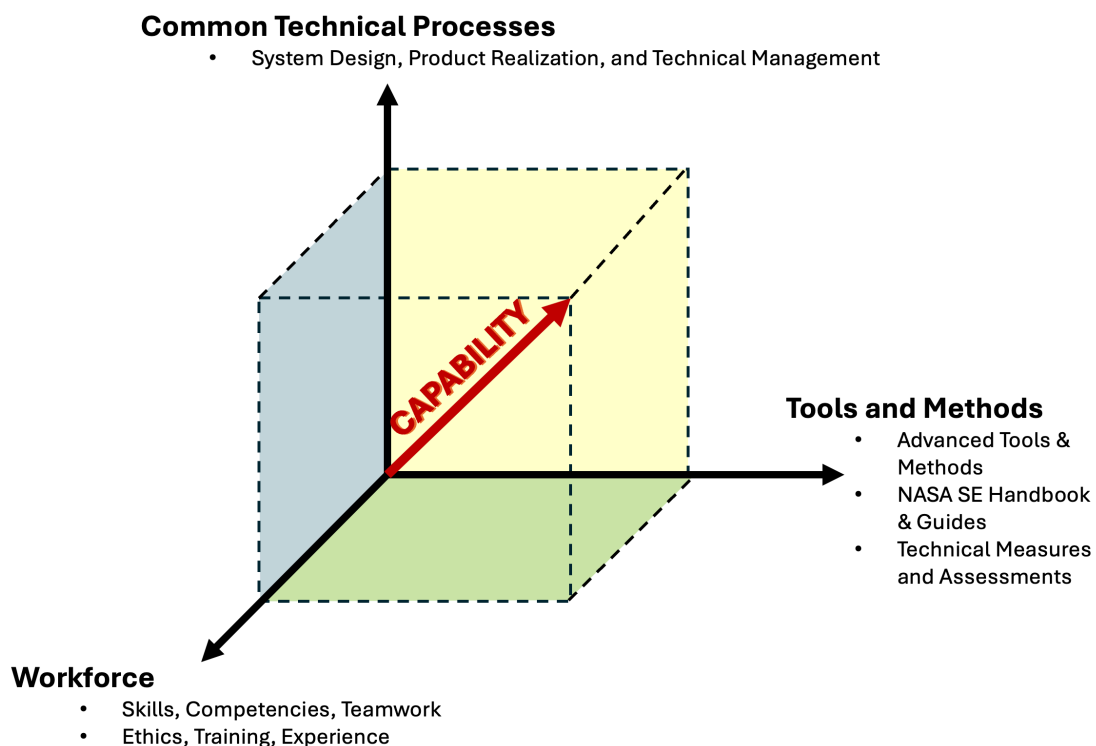


Figure 1. NASA's Systems Engineering Framework [15, p. 11]

The common technical processes are applied at each product layer to concurrently develop products that satisfy both mission functions and life-cycle support requirements [15, p. 20]. Figure 2 presents the three major processes of the NASA “Systems Engineering Engine.”

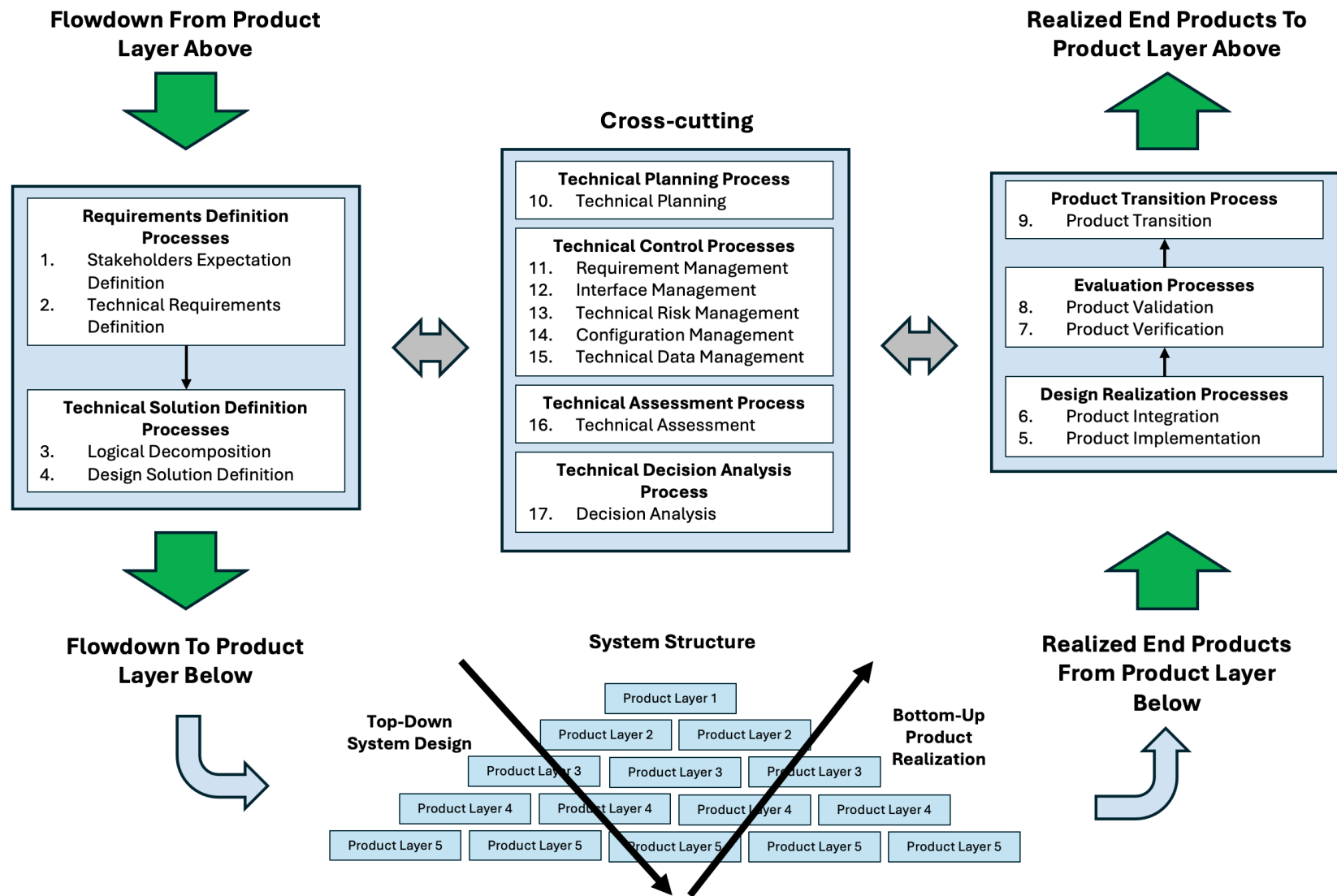


Figure 2. NASA's Systems Engineering Framework [15, p. 21]

At NASA, the system design process is applied at each product-based layer of the system structure and generally proceeds in the following order: (1) stakeholder expectation definition, (2) technical requirements definition, (3) logical decomposition, and (4) design solution definition [15, p. 22]. In this dissertation, “Stakeholder Expectations” are effectively synonymous with the “Needs Statement.”

1.2.3 Defining “The System”

Numerous definitions of the term “system” are applicable to NASA aircraft operations. Maier and Rechtin define a system as:

“A collection of things or elements which, working together, produces a result not achievable by the things alone” [4].

Blanchard and Fabrycky define a system as:

“A set of interrelated components working together toward some common objective or purpose. The set of components has properties and behavior that affect the properties and behavior of the set as a whole. Each component depends on the properties and behavior of at least one other component contained within the set, and each possible subset of components must exhibit at least two of the previously listed properties; the components cannot be divided into independent subsets” [10].

They further describe a fire department as an example of a total system, with components such as the building, fire engines, firefighters, communication equipment, and maintenance facilities [10]. This concept of a total system closely resembles NASA aircraft operations, in which mission-based goals include astronaut training, equipment and personnel transportation, and research [16].

Blanchard and Fabrycky also identify the fundamental elements of a system as components, attributes, and relationships. Components are the operating parts of a system and

include inputs, processes, and outputs. Attributes are the properties or observable manifestations of the system's components. Relationships are the links between components and attributes [10, p. 3]. NASA aircraft operations can be decomposed hierarchically using a top-down approach, from the overall Aircraft Operations Division value to the program level. At Johnson Space Center, each program is associated with a specific funding stream tied to an aircraft type or support function, including the Gulfstream V, Gulfstream III, T-38N Talon, WB-57 Canberra, Super Guppy Transport, depot maintenance, facilities, logistics, and engineering [17] [18].

Loper defines a system as “a combination of interacting elements organized to achieve one or more stated purposes” [13, p. 258]. That purpose may be product-oriented, service-oriented, process-oriented, or some combination thereof. This definition supports a systems-thinking perspective and is applicable to both physical systems and process systems. Material systems may range from a simple mechanical pencil to a complex launch vehicle. Systems engineering ensures that requirements are properly defined, architecture is established, standards are identified, interfaces are integrated, and the system is designed, verified, and validated using the systems engineering “Vee” model [10, p. 37] [19, p. 40] or comparable process models such as those proposed by Kossiakoff et al. [7, pp. 69-82]. These same principles can be applied to process systems and business operations. For example, the reintroduction of wolves into Yellowstone National Park required the ecosystem to be modeled as a system [20]. Because survival depended on relationships among species, a model was used to estimate the number of wolves needed to restore ecological balance. Similarly, process systems such as toll booths, cashier checkouts, or banking queues can be modeled with time as the key metric [21]. Service rates can be estimated statistically, and the number of operational stations can then be optimized based on customer demand. Too many stations produce inefficiency through underutilization; too

few create bottlenecks and cascading queues. Modeling and simulation can optimize such process-based systems [22].

Modeling begins by identifying the mental models to be improved rather than merely defining an efficiency target. System dynamics is closely related to problem-structuring methods. The primary distinction is that system dynamics provides an organizing framework for describing a system in a way that leads to a quantitative model [23]. To model a system effectively, its processes, metrics, and interdependencies must be understood well enough to ensure validity and accuracy.

1.3 System Dynamics Applications

System dynamics was founded by Jay Forrester at the Massachusetts Institute of Technology (MIT) in 1957 [24]. Unlike many other operational research tools, system dynamics can operate in both qualitative and quantitative modes. Wolstenholme describes qualitative applications through causal loop diagrams that characterize the structure of a system, followed by quantitative simulation using stock-and-flow networks [25]. Kunc describes two broad modes of system dynamics application: a descriptive mode, which resembles soft systems or problem-structuring approaches, and a predictive or prescriptive mode, which resembles hard analytical methods such as forecasting and optimization [24].

System dynamics may be used to model the technical performance of physical systems, event-driven business processes, or even non-material systems [1] [26]. A classic example often used in academic instruction is predator-prey population modeling. A basic model may begin with the stock of rabbits, whose population changes over time based on birth and death rates. Without constraints, the population may grow indefinitely or diminish to extinction. To improve

model fidelity, food supply constraints are introduced which would limit the number of rabbits. To further refine the model, a predator such as foxes may be added. These interacting stocks of vegetation, prey, and predator become interdependent through feedback loops. Figure 3 presents a classic example of such a system-based population model [27].

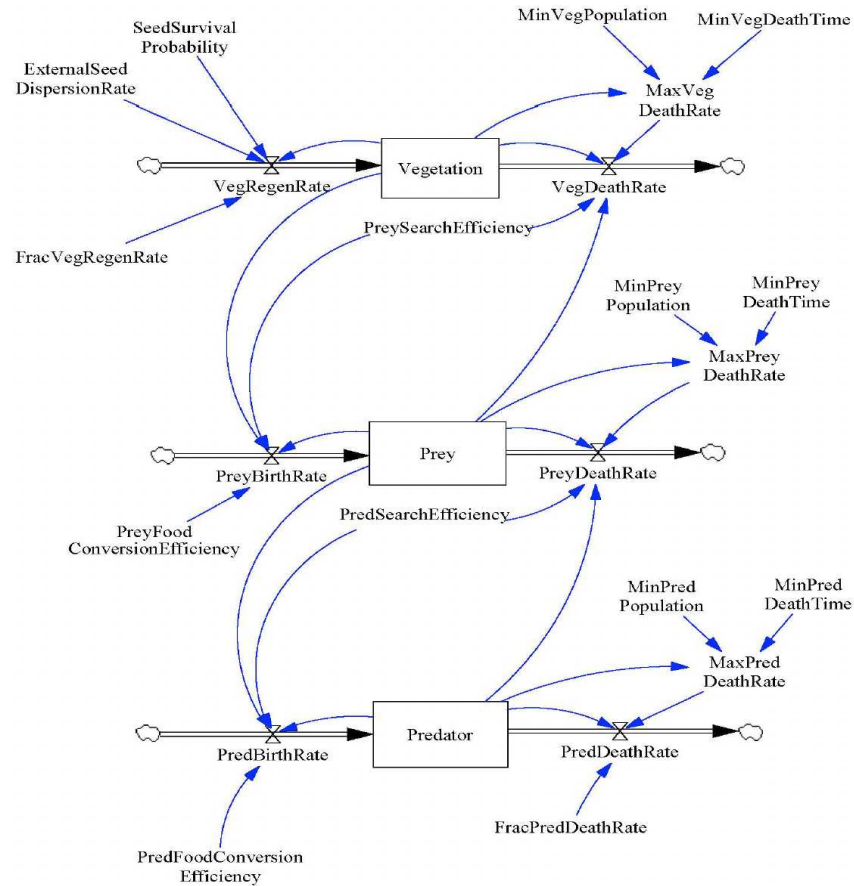


Figure 3. System Dynamics Example of Basic Predator/Prey Population Model [27]

Examples of non-material application of system dynamics are the optimization of a college course syllabus (Figure 4; *Appendix B*) [28] and a queueing system [21]. Although these are not physical production systems, using system dynamics modeling techniques can be used to replicate those specific system processes. In the case of the college syllabus optimization model, statistical studies of human learning and knowledge retention can be incorporated into the system dynamics model to determine the most effective approach to syllabus structure.

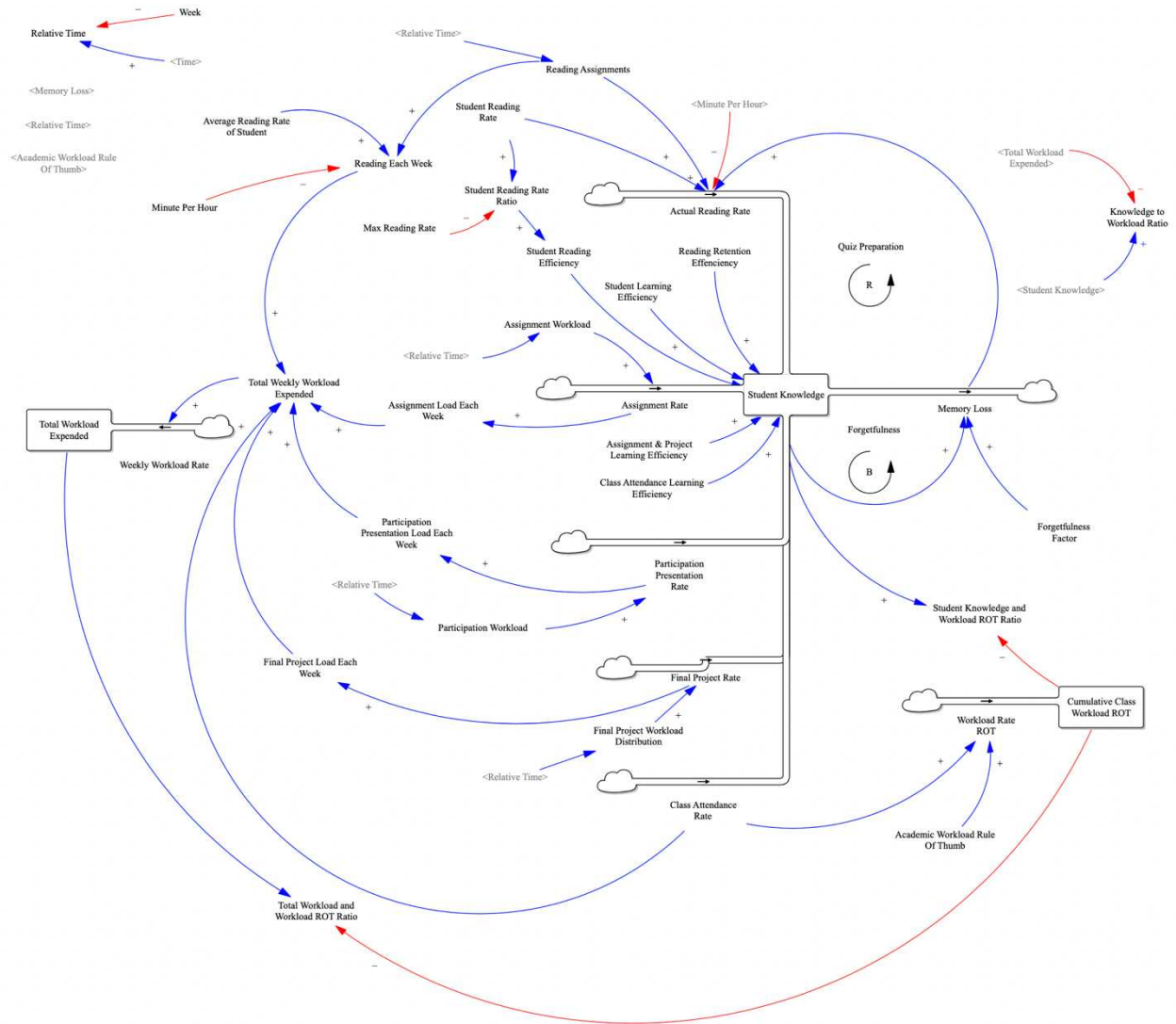


Figure 4. System Dynamics Example of College Syllabus Optimization Model [28]

A key requirement in any system dynamics application is the identification of primary performance metric to be observed and potentially optimized. In population models, this may be the number of living foxes, rabbits, or available vegetation (Figure 5) [29].

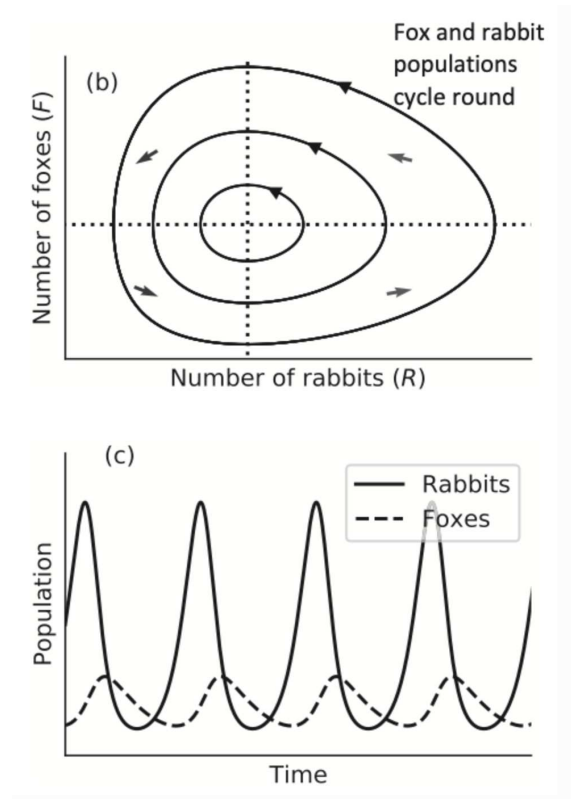


Figure 5. Results of Predator/Prey Population Model [29]

In the knowledge retention model, it is hours of knowledge retained by a student (Figure 6) [28].

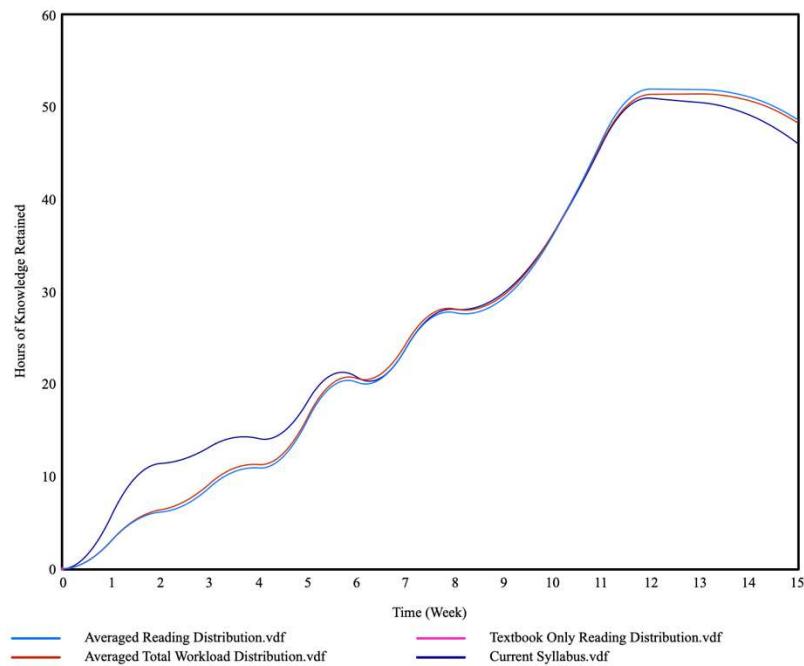


Figure 6. College Syllabus Optimization System Dynamics Model [28]

Financial process models are typically measured in currency when the objective is profitability, or in labor hours when the objective is efficiency. These two dimensions may also be linked through wage rates. Expenditures, revenues, and wages are usually represented in units such as USD/hour or USD/(flight hour). In such models, a stock may represent the current balance of funds available in an account. In the context of a business or government operation, that balance reflects financial conditions relative to inflows and outflows. At its most basic level, account value depends on the initial balance, the value of assets held, expenditure outflows, and revenue inflows.

To assess the overall value of an organization, assets must also be considered. For organizations that do not rely heavily on transportation or large infrastructure, these may consist primarily of facilities, real estate, and office equipment. In transportation and service organizations, however, major assets include aircraft, vehicles, machinery, and related infrastructure.

1.4 Application of System Dynamics in Businesses and at NASA

The System Dynamics Society defines system dynamics as a computer-aided approach for strategy and policy design intended to help people make better decisions in complex, dynamic systems [30]. When applied properly, system dynamics can model technological interfaces, organizational processes, human behaviors, populations, and many other system types [1] [14] [31]. In this dissertation, system dynamics is used to model business processes and quantify the monetary value of an organization.

NASA Aircraft Operations Division (AOD) at Johnson Space Center, located in Houston, Texas, has the mission of training astronauts, transporting personnel and cargo, and advancing

airborne science in a safe manner. NASA AOD can be characterized as a low-quantity, high-variation aircraft operations organization. NASA management could benefit from a modeling tool capable of projecting costs into future years and adjusting customer charge rates in ways that optimize safety, aircrew proficiency, and sustained operational capability. Other NASA centers maintain similar flight operations structures. Once a robust and validated AOD model has been developed, it may be adapted as a template for other NASA flight operations centers. The integration of these center-level models could ultimately support the development of a NASA Aircraft Operations Enterprise (NAOE) model [32]. An enterprise-level model would improve budget forecasting and scenario analysis at NASA Headquarters [33].

Such an enterprise model would include all NASA flight operations centers and would allow analysis of aircraft operations at the agency level. This capability would be valuable for Planning, Programming, Budgeting, and Execution (PPBE) submissions and for reallocating funding across centers [17]. It would also allow decision-makers to evaluate the potential benefits of investing in newer aircraft as the NASA fleet continues to age [16].

1.4.1 Potential Stakeholders

The intended audience for this dissertation includes organizations that operate relatively small aircraft fleets with high Type/Model/Series (T/M/S) variation (Table 1). Examples include the National Oceanic and Atmospheric Administration (NOAA), the United States Coast Guard (USCG), NASA, and Federal Aviation Administration (FAA)-certificated Title 14 Code of Federal Regulations (14 CFR) Part 141 flight schools. However, this research focuses specifically on NASA aircraft operations at Johnson Space Center in Houston, Texas.

Table 1. Classification of Aircraft Operations Globally

	High Variation	Low Variation
High Quantity	• NASA Enterprise • DoD Enterprise	• Commercial Airlines • Commuter Air Services
Low Quantity	• NASA Center Flight Operations • NOAA Flight Operations • 14 CFR Flight Schools • Commuter Air Services	• Commuter Air Services • DoD Squadrons • 14 CFR Flight Schools

The baseline model can also be modified to accommodate other aviation organizations, including those with high-quantity, low-variation fleets. The Department of War (DoW), for example, shares structural similarities with NASA AOD and often seeks to achieve a near net-zero financial position by the end of the fiscal year. In contrast, profit-oriented organizations such as commercial airlines typically maintain low fleet variation to reduce logistical complexity. Commuter air services may operate with either low quantity or low variation depending on their business model. When the DoW enterprise is broken down to the squadron level, aircraft T/M/S is typically standardized, and fleet size is relatively small.

The versatility of a baseline aircraft operations system dynamics model also makes it adaptable to organizations such as Part 141 flight schools. In that context, the objective would be profit optimization rather than budget execution. The model could estimate the minimum rental

hours needed to break even, the number of additional hours required to meet a target profit, and the sensitivity of the business to fuel price increases [34].

1.4.2 Current Business Models

Many texts address business dynamics, including Sterman's Business Dynamics [1]. Because many business processes are treated as linear, organizations often rely on spreadsheets or comparable tools to manage programs and resources. These tools can be useful, but they often make it difficult to visualize dynamic interactions and cascading effects [23]. As a result, managers and human resources personnel may not fully recognize the value of retaining system dynamics expertise within organizational decision processes.

Fielt defines a business model as "a model that describes the value logic of an organization in terms of how it creates and captures customer value" [35, p. 92]. Johnson et al. define a business model as one consisting of four interlocking elements: the customer value proposition, the profit formula, key resources, and key processes [36].

The concept of value may be defined monetarily, qualitatively, or personally [37]. The overall value of an organization should encompass all three dimensions. In a holistic sense, the business model boundaries of an aviation organization must be established to determine what characteristics define success or, conversely, where improvement is needed. When monetary, quality, and personal value dimensions are combined, the broadest overarching metric for an aviation organization may be described as value.

From a monetary perspective, organizational viability depends on revenue and assets [38]. From a quality perspective, the organization must maintain a positive reputation by meeting customer requirements. From a personal perspective, the organization must execute its

responsibilities ethically, professionally, and responsibly [39]. This dissertation primarily addresses the monetary component of organizational value, while recognizing that quality and personal dimensions are indirectly embedded in revenue generation. If quality or ethical performance is compromised, revenue and mission trust will likely decline.

1.5 Systems Engineering and System Dynamics Optimization

Businesses, organizations, and individuals can all suffer from uninformed and impulsive decision-making [40]. Aircraft operations are particularly complex and volatile. Inflation can directly affect an organization either immediately or with only slight delay [41]. Rising fuel and parts costs are felt as soon as procurement is required from external vendors. In many cases, these effects are immediate because preemptively purchasing and storing large inventories of fuel or parts creates its own financial burden. Consequently, many organizations rely on just-in-time logistics to minimize storage costs [42].

Staffing levels and wages are also variables that require careful optimization. Organizations must maintain an appropriate workforce size to achieve productive and sustainable performance [43] [44]. Overworked employees may leave for better opportunities, while underutilized employees may become disengaged and similarly seek other employment [45]. Salary determination likewise requires careful analysis of skills, duties, and experience [41]. Underpaying personnel contributes to attrition, while overpaying personnel may be unsustainable.

Customer pricing is also a delicate balancing problem. While pricing is influenced by supply and demand [46], it must also be sufficient to cover the organization's actual operating expenses. If customer charges are set too high, customers may seek alternative providers [43]

[45] [47]. The system dynamics model developed in this dissertation addresses this issue by varying customer charges through an initial rate and associated adjustment factors to examine resulting organizational effects.

Systems engineering seeks efficiency and optimization through design in order to satisfy established requirements [7] [13] [30] [48]. In existing operational systems, optimization may involve redesigning or restructuring processes that are already functioning. In classical mathematics, optimization is often associated with calculus, differential equations, and minimizing or constraining rates [49]. In practice, however, an optimized state may simply mean achieving a desired objective while avoiding saturation, instability, or operational failure. In private business, profit is often the primary performance goal [50]. In government organizations, where available funds are expected to be fully executed, a near net-zero financial position by the end of the fiscal year, or before funds expire, is typically the desired result [51] [52].

Systems usually contain combinations of linear inputs, outputs, stocks, and feedback loops. Feedback loops often indicate nonlinear behavior because they introduce accumulation and integration effects [23] [49]. Although business models may appear linear in isolation, they frequently exhibit nonlinear behavior when multiple interdependent states, feedback, and constraints are considered.

In large systems with many variables, flows, stocks, and states, overall behavior can become highly complex [48]. States may activate at different times, flows may start and stop at varying intervals, and resulting system behavior may be difficult to predict. System dynamics allows users to simulate these interactions over a defined time horizon and evaluate whether outcomes are desirable or unacceptable [24] [53].

1.5.1 Effects of Unsuccessful Resource Management

An organization's success depends on both financial viability and mission accomplishment [43] [47] [54]. In a government flight operations organization that seeks a full budget expenditure by the end of the fiscal year or before funds expire, failure to meet those goals carries significant consequences. At the most extreme, expenditures may go unpaid if there is insufficient revenue or reserve funding to cover debts [52]. One solution may involve requesting additional customer funds for unplanned requirements or seeking support from external stakeholders to absorb losses [17] [18] [55]. The effects of insufficient funds reverberate throughout the organization. Several of the most prominent consequences are listed below:

1) Grounding of Aircraft

If expenditures cannot be covered, aircraft operations are often suspended until additional revenue becomes available [56]. This is analogous to periods of government shutdown or furlough, as well as end-of-fiscal-year conditions in which budgeted flight hours have been exhausted early.

2) Reduction in Training

Managers may choose to reduce training for aircrew and maintenance personnel when funding is constrained. Required training may be deferred to the latest permissible date, and non-mandatory but beneficial courses may be cut to avoid overruns. Such reductions may create future safety concerns if the deferred training is important to personnel proficiency.

3) Reduction in Capability

Capability improvements require both time and money. If funding is unavailable, capability enhancements may be delayed, which can limit future mission opportunities. One

example is the installation of hush kits on the Gulfstream III for operations in European airspace. Because the modification was expensive, installation was deferred until funding became available, which temporarily restricted mission capability.

4) Decrease in Safe Flight/Ground Operations

Safety degradation is often an unavoidable consequence of financial shortfalls. When training, staffing, and capability are reduced, overall operational resilience decreases. The most severe option is workforce reduction, which forces fewer personnel to accomplish the same workload. Historically, mishaps, close calls, and hazards tend to increase under such conditions.

5) Cancellation of Program(s)

A program that persistently fails to operate within budget or meet mission requirements is likely to be cancelled in a government environment. In a profit-driven environment, the organization may become insolvent, be acquired, or cease operations altogether.

1.5.2 Effects of Successful Resource Management

A financially healthy organization, whether measured by profit or by disciplined budget execution, gains several important benefits. Several of the most prominent benefits are listed below:

1) Upgrading Aircraft

Additional funds allow aircraft to be upgraded, thereby increasing capability. For example, fleet modernization or avionics upgrades can improve range, mission flexibility, and operational safety.

2) Increase in Training

Additional funding enables aircrew and maintainers to attend advanced training and educational programs, thereby improving both safety and performance.

3) Improving Supply Chain Management

Parts availability is critical in aircraft operations. Marine Corps General Robert H. Barrow stated, “Amateurs talk about tactics: the professionals study logistics” [57]. Although this was geared towards warfare, it also applies to organizations. If parts are not available, aircraft do not fly. Additional funding allows organizations to stock ready-for-installation components or secure effective vendor agreements, thereby reducing downtime and improving reliability [58].

4) Purchasing New Aircraft and Capabilities

Every organization should maintain a roadmap for fleet modernization. Such a roadmap should address who will sponsor the effort, what aircraft will be acquired, when transition will occur, where the aircraft will be based, and why the replacement is operationally justified. These decisions must be validated against key performance parameters and operational requirements [3, p. 481].

5) Increase in Safe Flight/Ground Operations

Organizations with stable or optimized financial performance can invest in better equipment, improved processes, and stronger safety programs, thereby creating safer working environments for personnel [59].

1.6 NASA Aircraft Operations

NASA's aircraft operational mission, as stated in NASA Procedural Requirement (NPR) 7900.3D, is that "NASA's aircraft are generally used for research and development, program support, and passenger transportation, and many NASA aircraft fly multiple missions. NASA maintains only the number of aircraft to enable the Agency to meet its mission requirements that are linked to the Agency's Strategic Plan" [16]. These operations support aeronautics research, earth and space science, space exploration, science and technology demonstration, astronaut training, range surveillance, launch support, contingency response, and mission-required travel [16]. Table 2 presents the detailed mission requirements identified in NPR 7900.3D.

The NPR further states that passenger transportation flights may be classified as mission required only when failure to use a NASA aircraft would negatively affect a NASA operational mission, prevent timely response to an accident, or threaten the health and safety of NASA personnel, and only when commercial or ground transportation cannot satisfy that need [16].

Multiple additional NPRs apply to aircraft operations, each focused on specific responsibilities. For example, the JSC Aviation Safety Office relies on NPR 7900.3D Aircraft Operations Management [16], NPR 8621 Mishap and Close Call Reporting, Investigating, and Recordkeeping [60], NPR 8000.4C NASA Agency Risk Management Processes [61], NPR 8715.1B NASA Safety and Health Program Requirements [62], NPR 1800.1D NASA Occupational Health Program Procedures [63], and NASA Policy Directive (NPD) 8700.1F NASA Policy for Safety and Mission Success [64] when executing its responsibilities. Additional NPRs and NPDs must be consulted for specialized areas of interest.

Table 2. NASA Agency Aircraft Mission Requirements [16]

Space Operations
a. Return International Space Station crews after landing.
b. Provide transportation for emergency response to in-space operations problems and unexpected events.
Space Program
c. Transport critical launch management personnel to and from U.S. and international launch sites.
d. Transport critical commercial space hardware and equipment before or after landing in U.S. and international locations.
e. Provide emergency transportation capability for response team for each manned space mission launch or landing.
f. Provide transportation capability for initial response to space vehicle post-mishap investigations.
g. Needed for emergency response to in-space operations and unexpected events (unscheduled and time-critical events).
h. Provide transportation of the dependent families of the astronaut crewmembers to and from launches and landings.
i. Provide transportation for prime flight crew members to/from launch site during pre-launch countdown and post-launch activities.
Science Programs
j. Transport emergency response teams and equipment to flight research mishaps or aircraft grounded off station due to maintenance problems.
k. Return hardware and data from the landing site of remotely operated space probes.
l. Transport equipment to support flight research for unscheduled and time-critical events to accommodate tight launch schedules.
m. Provide contingency, fast-response capability for launch and search and recovery operations for sounding rockets launched from the Wallops Island range.
Natural Disaster Response
n. Hurricane and other natural disaster evacuation and response to protect NASA personnel and property.

1.6.1 NASA JSC (Center-Level) Aircraft Operational Requirements

Johnson Space Center (JSC) maintains directives specific to aircraft operations within the Aircraft Operations Division (AOD), located at Ellington Airport in Houston, Texas. These local requirements must be at least as stringent as NASA Procedural Requirements (NPRs); while they

may be more restrictive, they cannot be less so and must be strictly adhered to. Compliance is evaluated through a biannual peer-review conducted by the Inter-Agency Aircraft Operations Program (IAOP) [16] [60], ensuring alignment with both Center-level and Agency-level requirements.

Within AOD, Aircraft Operations Procedures (AOPs) establish the governing standards for each aircraft. These documents define mandatory training, currency requirements, and operational responsibilities. The primary AOP pertains to the T-38(N) jet trainer, as astronaut training constitutes the division's primary mission (AOD 09295 Vol. 1 [65]). The system dynamics model developed in this dissertation incorporates these requirements, including minimum flight hours and proficiency standards for aircrew.

In addition to operational directives, the Aviation Safety Office (ASOFF) establishes safety requirements through local directive ASO 33887 [66], which serves as the division's Safety Management System (SMS).

All operational, maintenance, and training data are managed through the NASA Aircraft Management Information System (NAMIS). This system ensures compliance in aircrew scheduling, facilitates maintenance tracking, and supports the collection of operational metrics.

1.6.2 Current Assets of NASA JSC Flight Operations

1) Aircraft Assets

During the period relevant to this dissertation, JSC's aircraft inventory included one Gulfstream V, one Gulfstream III, one Super Guppy Transport (SGT), three WB-57F Canberra aircraft, and twenty T-38N Talons. More recently, the Gulfstream III and six T-38N aircraft were

decommissioned. Additionally, eight TH-57 Sea Ranger helicopters were loaned from the U.S. Navy to support lunar landing training.

The Gulfstream V (Figure 7) serves as the primary platform for Direct Return missions [67], transporting astronauts from Kazakhstan to Houston within 24 hours of reentry from space. The aircraft is equipped with medical accommodations and has been adapted for domestic missions following the introduction of U.S.-based crewed space launches and landings. It was further modified with nadir windows to support Airborne Science Program (ASP) missions [68].



Figure 7. NASA's Gulfstream V at Johnson Space Center [67]

The Gulfstream III (Figure 8), formerly a secondary Direct Return aircraft [69], also served as a key airborne science platform. It was highly modified with external sensor pods (Ka-, L-, and P-band), a capability unique within the fleet. Although decommissioned in 2024, similar aircraft from other NASA Centers continue to support operations [70].



Figure 8. NASA's Gulfstream III at Johnson Space Center [69]

The Super Guppy Transport (Figure 9) provides heavy-lift capability, with a payload capacity of approximately 48,000 pounds. It is used to transport large cargo such as spacecraft components and oversized equipment [71] [72].



Figure 9. NASA's Super Guppy Transport at Johnson Space Center [71]

The WB-57F Canberra (Figure 10) supports high-altitude operations exceeding 60,000 feet and is used for research, astronaut training, and Department of War missions. It plays a critical role in atmospheric data collection and reentry observation [73] [74].



Figure 10. NASA's WB-57F Canberra at Johnson Space Center [73]

The T-38N Talon (Figure 11) is the primary aircraft for Space Flight Readiness Training (SFRT). It is used to train astronauts in high-performance flight environments and for crew resource management exercises. At the time of this study, aircrew personnel at AOD included

research pilots, flight science officers (FSO), sensor equipment operators (SEO), veteran astronauts, and astronaut candidate trainees [75].



Figure 11. NASA's T-38N Talon at Johnson Space Center [75]

The TH-57 Sea Ranger helicopters (Figure 12), introduced to AOD in 2025, are intended to support Artemis lunar landing training. While not yet being currently flown at AOD nor incorporated in the system dynamics model, they represent a future capability expansion.



Figure 12. TH-57 Sea Rangers at Johnson Space Center [76]

2) Facilities and Equipment Assets

The Committee on NASA’s Strategic Direction states, “Rising costs associated with increasingly complex missions, declining science budgets, international partnerships that fell apart, and mission cost overruns have strained science budgets to their breaking point.” They also state, “The NASA aeronautics program has made important contributions to national priorities related to the U.S. air transportation system, national defense, and those portions of the space program that include flight through Earth’s atmosphere. However, the budget for NASA’s aeronautics program shrank significantly in the 2000-2010 decade, and the full historically demonstrated potential of the aeronautics program is not being achieved given the current levels of funding” [77].

NASA JSC’s Aircraft Operations Division has adjusted to the above condition by performing reimbursable work externally such as depot-level overhauls, internal non-destructive inspections, and other engineering efforts to bring in additional funds from external customers.

JSC’s Aircraft Operations Division maintains a self-sustaining infrastructure, including logistics, engineering, maintenance, and non-destructive inspection (NDI) capabilities. Located primarily at Ellington Airport (EFD), the division also operates a depot-level maintenance facility located at the El Paso International Airport (ELP); capable of performing full aircraft overhauls.

To offset budget constraints, AOD engages in reimbursable work, including maintenance and repair services for U.S. Air Force and Navy aircraft. For a more detailed description of the missions flown and maintenance performed at the AOD, ***Appendix C*** encompasses a presentation that was presented in 2022.

NASA's Engineering Branch performs engineering projects through "Public Use" aircraft modifications. This enables research equipment to be designed, integrated, and flown on NASA aircraft for missions supporting Direct Return, Space Flight Readiness Training Program, and Airborne Science Program missions. When the aircraft flies FAA 14 CFR PART 91 operations, the aircraft is reconfigured to FAA 14 CFR PART 91 standards before carrying non-aircrew passengers.

3) *Personnel Composition*

AOD operates on a standard weekday schedule with supplemental maintenance shifts to support extended operations. At the time of this study, the division employed approximately 285 personnel, including engineers, pilots, maintainers, and support staff (Figure 13).



Figure 13. NASA JSC Aircraft Operations Division and the Astronaut Office (taken in 2024)

Research pilots are multi-qualified across multiple aircraft platforms and are responsible for astronaut training, flight evaluations, and mission execution. Their primary role is to support the T-38N training program, funded through Human Exploration and Operations (HEO) which encompasses Space Flight Crew Operations (SFCO) [65]. Research pilots also fly missions

anywhere in the Continental United States (CONUS) and in austere environments throughout the world. Most of these missions are funded by inter-agency (NASA) funding transfers or DoW Military Interdepartmental Purchase Request (MIPR) transfer streams [78].

1.6.3 Assessment of Aircraft Capabilities

An assessment of the aircraft at JSC was performed based on each aircraft's capabilities. This assessment allows customers to select the "best fit" aircraft for the job and is included in this paper. The Cost Per Flight Hour (CPFH) will also be an important factor, but to gather the required data or successfully complete a specific mission, the capabilities must be considered.

The categories assessed were Experimentally Modular, Experimental Payload Capability, Airspeed Regime Capability, Passengers Onboard (MAX), Altitude Regime Capability, and Maximum Range. The categories used quantities that related to each to allow a comparison between platforms.

Experimentally modular is the ability of the aircraft to change configurations to accommodate mission equipment without the need for additional structural modification to the aircraft. This metric is defined by percentage of modularity. A "10%" modular aircraft (i.e. T-38N) has very little capability to house research equipment for Airborne Science flights. A highly modular aircraft, such as the WB-57F and the Gulfstream III is close to "95%" modular and can house Airborne Science equipment without the need for major structural modification. Figure 14 shows a spider chart for the aircraft at JSC.

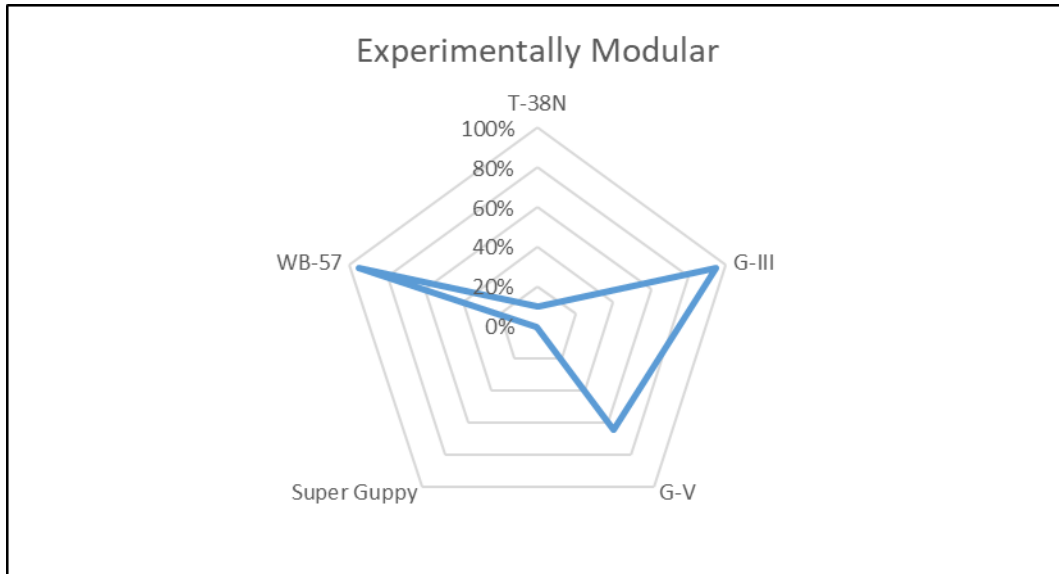


Figure 14. NASA Johnson Space Center Aircraft's Modularity

Payload capacity describes the ability of an aircraft to carry or transport parts or science equipment. Figure 15 shows the capabilities of the aircraft at JSC. As shown, the Super Guppy dominates this capability. Conversely, the T-38N does not have much capacity to carry payload. The T-38N's limiting factor for payload is space available since it is a supersonic jet trainer and is very streamlined.

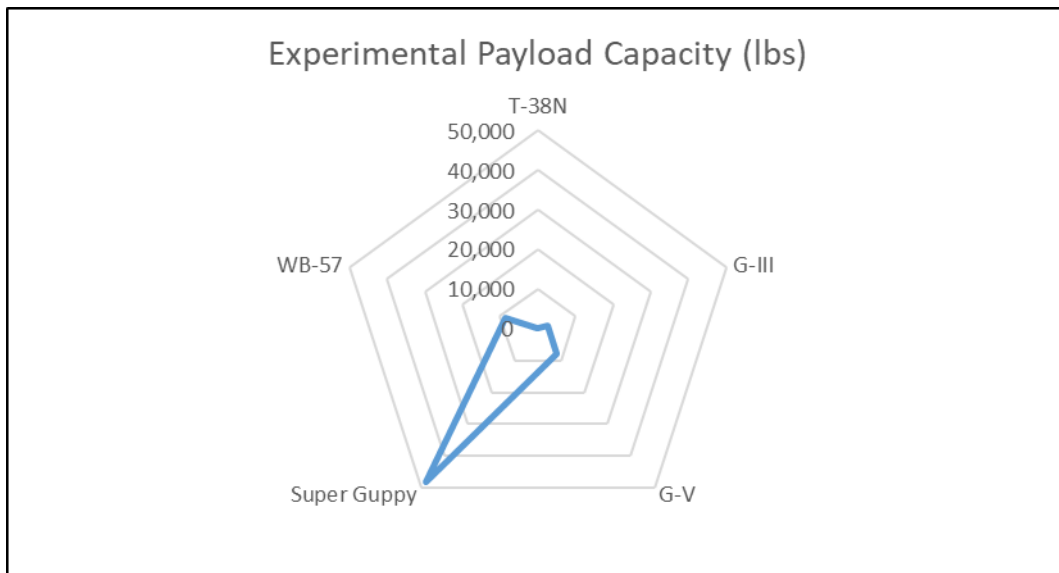


Figure 15. NASA Johnson Space Center Aircraft's Experimental Payload Capabilities

The Airspeed regime is grouped into three categories to allow comparison. The units of this comparison are in percentages that the aircraft flies normally within these airspeed categories. Each aircraft's high, medium, and low-speed regime percentages sum to total 100%. For example, in Figure 8, the T-38N flies 80% of a normal flight greater than 250 knots. For 20% of the flight, it is within the 150-250 knots band. It only flies below 150 knots on landing touch down; therefore, it is 0% in the low-speed regime. The high-speed category was determined to be an aircraft capable of flying faster than 250 knots. The low-speed category is an aircraft that flies normal operations slower than 150 knots. The medium speed category is an aircraft with normal operating range between 150-250 knots. Figure 8 compares all aircraft types at JSC.

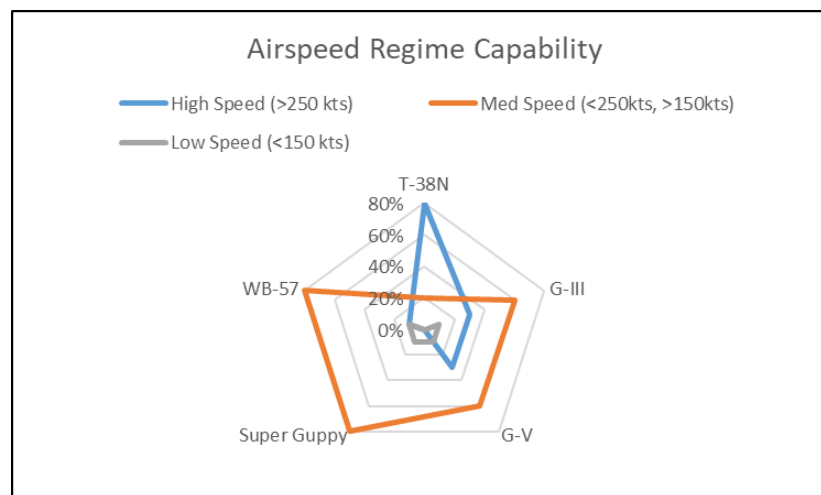


Figure 16. NASA Johnson Space Center Aircraft's Airspeed Regime Capabilities

The Airborne Science Program and Department of War have a need to test military systems or gather atmospheric data in the high-altitude, medium-altitude or low-altitude flight regimes (Figure 17). Only two NASA Centers have the capability of flying manned aircraft above 51,000 feet. Above 50,000, single piloted aircrew are required to wear special pressure suits. At JSC, the WB-57 can go higher than 60,000 feet. The altitude flight regimes are grouped

into three categories: High-Altitude (>30,000 feet), Medium-Altitude (<30,000 but greater than 10,000 feet), and Low-Altitude (<10,000 feet). The percentages detail the normal time percentage that the aircraft flies within those bands. The WB-57F dominates the high-altitude regime. The Super Guppy usually flies low to medium altitude while carrying cargo (only the cockpit is pressurized).

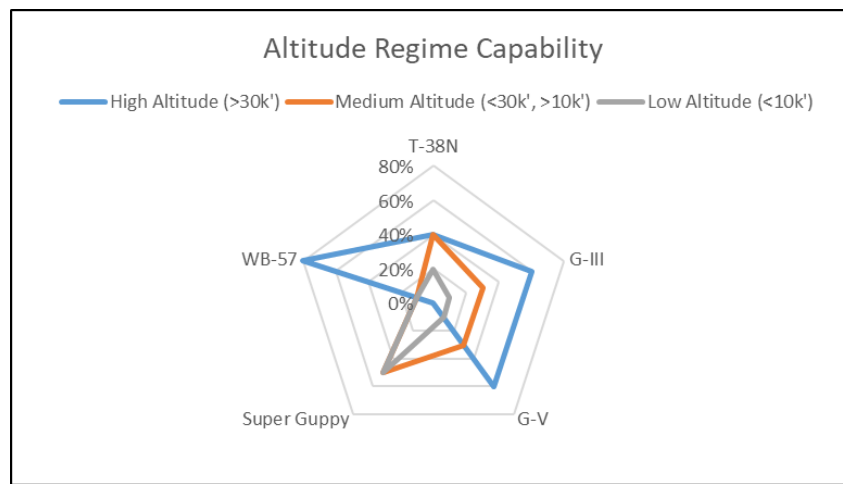


Figure 17. NASA Johnson Space Center Aircraft's Altitude Regime Capabilities

The range of an aircraft is an important capability when deciding which aircraft is suitable for a specific mission. For instance, the Direct Return mission is ideal for the Gulfstream V since it has the capability to fly further (almost 6,000 miles) and can carry more passengers. The Gulfstream III can do the mission, but not as efficient as the Gulfstream V. The T-38N can go fast to a location but only has a maximum range capability of 650 nautical miles. Figure 18 details the maximum range capabilities of the aircraft at JSC.

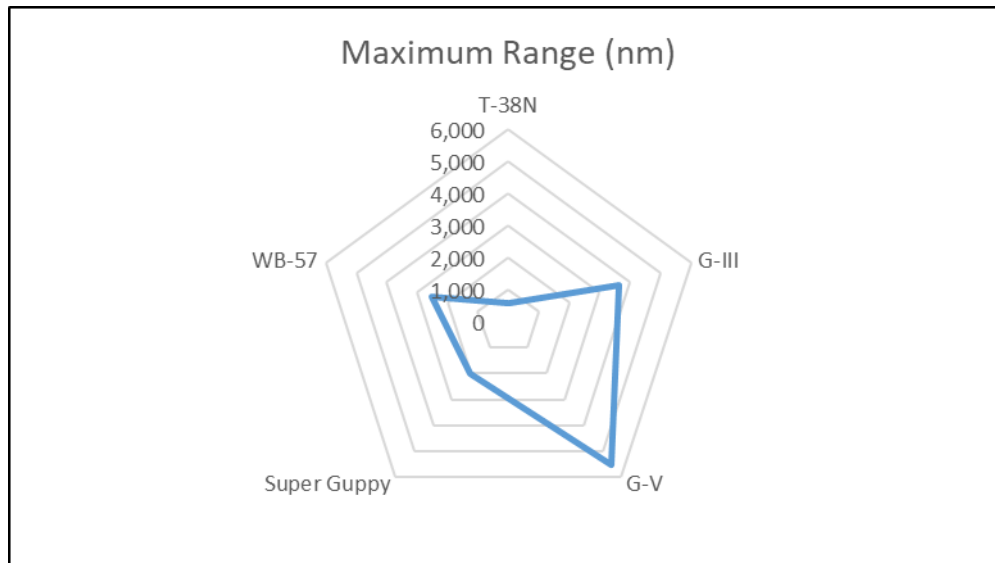


Figure 18. NASA Johnson Space Center Aircraft's Maximum Range Capabilities

The final capability assessed is the passenger carrying capabilities of each aircraft. In Figure 19, the business jets at JSC can carry the most personnel since they are designed to carry passengers. The T-38N and the WB-57F were manufactured with only two crew seats. This is a factor when performing science flights in the WB-57 since the rear cockpit will be a sensor equipment operator (SEO) assigned to JSC that will run the experiments and must be qualified in the aircraft. The SEO must have a working knowledge of the systems being flown or tested. Conversely, science experiments flown on the Gulfstream V or III allow the scientists to fly in the cabin of the aircraft and operate their own equipment when gathering data. Although this capability doesn't seem to be an important factor at initial glance, it is extremely important to the successful execution of airborne science flights.

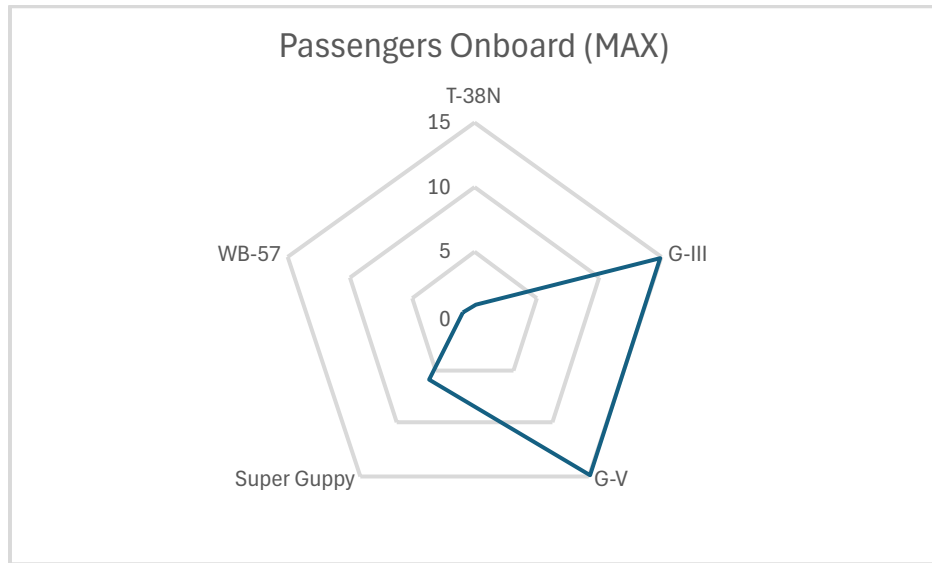


Figure 19. NASA Johnson Space Center Aircraft’s Maximum Passengers Onboard Capabilities

All capability factors must be weighed and evaluated to determine the best platform for the mission. Trade-offs are made and alternatives provided to meet a capability. If a capability cannot be made and is required, the customer will seek other organizations for their experiment. For example, if the Gulfstream modularity is the primary capability desired (i.e. the customer does not want to modify the jet to accommodate their equipment if flown on a different aircraft), and the aircraft is to be flown at low altitudes (1,000-5,000 ft), then the range of the aircraft will be sacrificed. Additional fuel stops will be required; hence, a trade-off.

1.6.4 NASA Enterprise Aircraft Operations Composition

The NASA Enterprise is a compilation of all aircraft operations offices and divisions within each NASA Centers. At the time of this paper, the NASA Centers that have aircraft operations are: 1) Johnson Space Center (Houston, Texas), 2) Armstrong Flight Research Center (Edwards AFB, California), 3) Glenn Research Center (Cleveland, Ohio), Wallops Flight Facility (Goddard Space Flight Center, Maryland and Wallops Island, Virginia), Langley Research Center (Langley, Virginia), and Kennedy Space Center (Titusville, Florida) (Figure

20). The other Centers and partnership locations that aren't listed above do not have aircraft but can contribute to the success of aircraft operations [79].

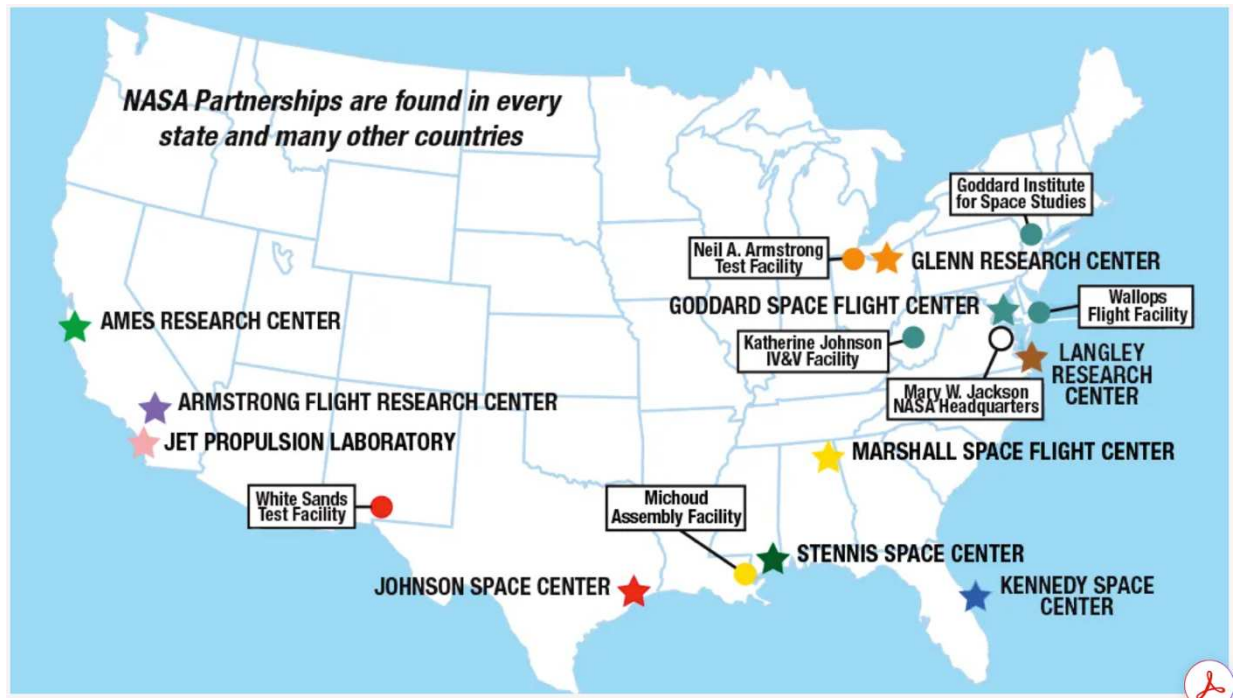


Figure 20. Geographical Map listing the NASA Center and Partnerships [79]

1.6.5 Funding Streams and Costs at Johnson Space Center's Aircraft Operations Division

Business aviation contributes approximately \$150B USD to the U.S. economy and supports more than 1.2 million jobs [80]. In fiscal year 2025, the enacted budget for military aircraft and related systems totaled \$44.3B USD [81]. Aircraft operations are inherently resource-intensive; however, when managed effectively, they can yield substantial operational and financial benefits. Consequently, cost, revenue, and fee structures are critical metrics for ensuring both operational efficiency and safety. For this reason, the primary unit of analysis in this dissertation is the United States Dollar (USD).

Department of War (DoW) and other federal aviation organizations, including NASA, operate under non-profit budgetary frameworks. These organizations request funding based on

projected operational needs; however, allocated budgets are often less than requested amounts. Accordingly, organizations must execute their missions efficiently while ensuring that allocated funds are fully and properly expended within the fiscal period.

Within the Aircraft Operations Division (AOD) at Johnson Space Center (JSC), each program operates under both forecasted and allocated budgets. Additionally, programs may perform reimbursable work, generating supplemental revenue that can support both aircraft and non-aircraft operations [17]. Excess funds generated through reimbursable activities may be reinvested in infrastructure, asset upgrades (e.g., aircraft or equipment), or used to reduce the cost per flight hour charged to customers. The financial objective of a federal aviation organization is to maintain a value at the end of the fiscal year (FY) that is equivalent to the initial value, adjusted for capital improvements, asset upgrades, and inflation. These financial dynamics can be modeled using system dynamics tools such as VensimPLP®, reinforcing the use of USD as the primary modeling unit.

NASA Procedural Requirement (NPR) 9470.1, NASA Budget Execution, governs the commitment, obligation, and expenditure of funds within the agency [17]. NASA employs the Planning, Programming, Budgeting, and Execution (PPBE) process to secure and manage funding. This process incorporates a hybrid “bottom-up/top-down” approach. The Congressional Operating Plan (COP) represents NASA’s high-level budget submission to Congress, while the Agency Operating Plan (AOP) provides a more detailed internal allocation of resources across programs and projects. The Agency Execution Plan (AEP) further refines this structure by detailing the expected funding authority for the execution year [17].

At JSC’s AOD, funding requirements are coordinated with the Astronaut Office and submitted through the International Space Station (ISS) Program Office under Human

Exploration and Operations (HEO) funding. These requirements are processed through the AEP, AOP, and ultimately the COP. Operational funding for JSC's Aircraft Operations Division and the T-38N program are categorized as Space Flight Crew Operations (SFCO) funding.

International partners, including the Japan Aerospace Exploration Agency (JAXA), European Space Agency (ESA), and Canadian Space Agency (CSA), provide funding for astronaut training flights, which is routed through the ISS Program Office to AOD for execution.

Other aircraft programs, such as the WB-57, Gulfstream III, Gulfstream V, and Super Guppy Transport, may also utilize SFCO funding when supporting spaceflight training or transportation missions. Representative examples include high-altitude WB-57 flights for pressure suit training, Gulfstream aircraft supporting Direct Return missions, and the Super Guppy transporting large payloads such as the Orion crew module.

Reimbursable work within AOD is evaluated on a case-by-case basis and must comply with Federal Acquisition Regulations (FAR). Depending on the scope and cost, procurement processes may involve Requests for Information (RFI), Requests for Quotation (RFQ), or formal source selection procedures. Common reimbursable activities include depot-level maintenance for DoW T-38 aircraft, funded through Military Interdepartmental Purchase Requests (MIPR), as well as specialized WB-57 mission support.

Aircraft cost metrics are tracked using the NASA Aircraft Management Information System (NAMIS), which leverages historical data to compute Cost Per Flight Hour (CPFH). Generally, increased annual flight hours reduce CPFH due to cost distribution; however, higher utilization accelerates maintenance requirements, including scheduled inspections and Programmed Depot Maintenance (PDM). These factors must be incorporated into cost forecasting and customer pricing.

Aircraft operating costs can be modeled using total cost (TC), which is composed of fixed costs (FC) and variable costs (VC). Vasigh et al. propose modeling TC as a cubic cost function [47]:

See *Equation (1)* below:

$$\text{The Cubic Cost Function: } TC = a + bQ + cQ^2 + dQ^3 \quad (1)$$

$$TC = FC + VC \quad (2)$$

$$a = FC \quad (3)$$

$$VC = bQ + cQ^2 + dQ^3 \quad (4)$$

Where:

a, b, and d > 0

c < 0

c² < 4bd

Q = total number units produced

b = average cost component per unit

FC is Fixed Cost

VC is Variable Cost

The TC can be estimated by historical trends and using a Best Fit function where “a” is the FC of aircraft operations for the specific program and Q would be flight hours flown. “b” would be the VC per flight hour, and “c” and “d” are unknowns without using a fitting function.

NAMIS serves as the primary enterprise resource planning and mission support system for AOD, integrating flight operations, maintenance, and logistics [65]. It enables detailed tracking of operational costs, consumables, flight hours, and aircraft availability. This data

supports accurate cost modeling and operational decision-making. Using NAMIS, the details of an aircraft's cost to operate can be determined.

Vasigh et al. categorizes airline fixed and variable costs as [47]:

1) *Fixed Cost*

- Fixed salaries, benefits and training costs for flight crews, which do not vary according to aircraft usage
- Maintenance costs
- Maintenance labor for maintenance scheduled on an annual basis
- Maintenance contracts for maintenance scheduled on an annual basis
- Lease costs based on a length of time
- Depreciation
- Operations overhead
- Administration overhead
- Self-insurance costs

2) *Variable Cost*

- Crew costs (travel expenses, overtime charges, wages of crew hired on an hourly basis or part-time basis)
- Maintenance costs scheduled on the basis of flying time or flight cycles
- Maintenance labor (includes all labor salaries, wages, benefits, travel, training)
- Maintenance parts (cost of materials and parts consumed in aircraft maintenance and inspections)
- Maintenance contracts (all contracted costs for unscheduled maintenance, maintenance scheduled on flight-hour basis, on flight-cycle basis or on condition)
- Engine overhaul, aircraft refurbishment, major component repairs
- Modifications
- Fuel and other fluids (hydraulics fluid, oil, etc.)
- Lease costs (leasing costs based on flight hours)
- Landing fees, airport and enroute charges.

Consistent with Vasigh et al. [47], fixed costs include expenses that do not vary with flight activity, such as salaries, annual maintenance contracts, depreciation, and administrative overhead. Variable costs, in contrast, scale with operational usage and include fuel, flight-hour-based maintenance, consumables, and mission-specific expenses. A practical method for

distinguishing between these categories is to consider a hypothetical scenario in which all aircraft operations are suspended. Costs that persist under this condition are classified as fixed, whereas those that cease are variable.

In the system dynamics model developed in this dissertation, total costs and funding flows are initially implemented at a high level to validate system behavior. Subsequently, more granular cost components are introduced to enable sensitivity analysis and scenario-based optimization, including variations in fuel prices, flight hours, asset obsolescence, and fleet expansion.

1.6.6 Business Case Applied to NASA JSC Flight Operations

The Committee on NASA’s Strategic Direction conducted a comprehensive assessment of the Agency’s long-term trajectory, concluding that “NASA cannot execute a robust, balanced aeronautics and space program within the current budget constraints... In addition, individual NASA centers are finding it necessary to selectively reduce their infrastructure or identify alternative means of support, such as through external collaborations. External partnerships can be highly beneficial, particularly in the current fiscally constrained environment, and may enable NASA to execute a robust and balanced aeronautics and space program without additional funding” [77].

Since 2012, NASA’s financial landscape has evolved modestly with the introduction of Commercial Crew programs, continued reliance on Soyuz, sustained International Space Station (ISS) operations, and the development of Artemis and lunar surface initiatives. However, most of the incremental funding has been directed toward human spaceflight programs (the “Big S” of NASA), rather than aeronautics (the “Little A” of NASA).

Across the continental United States, NASA operates six Aircraft Operations Centers whose fleets support global missions. While each center maintains unique mission requirements, their Aircraft Operations Divisions/Offices share common structural characteristics, including Operations and Sustainment (O&S) costs, customer demand profiles, and funding mechanisms. Future extensions of the system dynamics model developed in this dissertation will establish a generalized baseline representation of NASA Aircraft Operations. This baseline framework can be modified to center-specific configurations, enabling both individual and aggregated modeling of flight operations within a unified NASA Aircraft Operations Enterprise (NAOE) model.

The systems engineering methodology guiding this effort emphasizes requirements analysis and baseline architectural development. Notably, NASA Procedural Requirements (NPR) 7900.3D, Aircraft Operations Management, does not prescribe a formal architectural framework for aircraft operations. Instead, it defines mission objectives, assigns organizational responsibilities, establishes maintenance and airworthiness standards, and outlines aircrew training and currency requirements [16].

Building upon these systems engineering principles, this research advances the development of a system dynamics model of the NASA Johnson Space Center (JSC) Aircraft Operations Division. The model captures financial inflows and outflows associated with operational activities, representing both exogenous and endogenous monetary dynamics within a stock-and-flow structure [17] [18]. Following validation and verification, the model will be used to evaluate operational scenarios aimed at improving efficiency and resource allocation.

Potential scenarios include fleet modernization initiatives, such as replacing the aging T-38N with the U.S. Air Force T-X trainer, substituting the Super Guppy Transport with the Airbus A300 Beluga, or upgrading the Gulfstream fleet with additional Gulfstream V aircraft.

Workforce adjustments, including increased pilot staffing or expanded reimbursable workloads (with corresponding maintenance and support personnel growth), can also be examined. The model is intentionally modular to support a broad range of future scenario analyses.

Socioeconomic and geopolitical events can exert immediate and significant impacts on aviation operations. Notable examples include the September 11, 2001, terrorist attacks, the COVID-19 pandemic, and the Russian invasion of Ukraine. This dissertation examines the effects of the COVID-19 pandemic and the Russia–Ukraine conflict in detail in Chapter 3, analyzing their implications for operational performance and resource management within NASA aircraft operations.

1.7 Needs Statement Definition

Time-critical and poorly informed decisions have contributed to the decline of many enterprises, and aviation-based organizations are no exception. Efficiently operating an aviation organization is especially challenging because demand fluctuates substantially in response to both internal and external variables [82]. Complexity increases even further at the enterprise level, where debt, uncertainty, demand reductions, and occasional bankruptcies have characterized the broader aviation market [83]. At the same time, the industry faces major sustainability challenges, including the development of new aircraft technologies, increased use of alternative and renewable fuels, air traffic management improvements, and trajectory optimization [84]. Under these conditions, decision-makers in aviation organizations often struggle to assess the relative value of competing decisions because those decisions must account for both known factors and known unknowns, as well as their projected impacts over future years.

The financial and operational aspects of maintaining and operating large aircraft fleets have been studied extensively. Less attention has been given to organizations that operate relatively small fleets with high Type/Model/Series variation, such as NOAA, the USCG, NASA, and FAA-certificated Part 141 flight schools. Existing analyses of aircraft operations tend to focus on technical optimization topics such as availability, reliability, and scheduling rather than optimization of the organization as a whole [2] [6] [8].

A central purpose of systems engineering is to identify a requirement, formulate a needs statement, and design a system capable of addressing that requirement. In aircraft operations, the number of variables that influence decision-making is substantial, and these variables must support both sustainability and, in some contexts, profitability. Even in net-zero organizations, a modest positive financial condition may enable reinvestment in infrastructure, compliance, and capability enhancement. Historically, program managers have often focused primarily on their own stove-piped areas of responsibility. However, effective decision-making in aircraft operations requires synergy across specialties, platforms, logistics, staffing, funding movements, and temporary mission support mechanisms.

Decision-makers have traditionally relied on tools such as Microsoft® Project and Microsoft® Excel to manage programs. Microsoft® Project is useful for scheduling and some aspects of budget forecasting, while Excel is effective for budget management. However, Excel does not integrate scheduling well, can be prone to user input errors, and does not inherently verify unit consistency.

A modeling and simulation tool capable of integrating schedule, financial, and operational behavior would therefore provide significant value. Once such a model has been

validated and verified, a dashboard can be used to vary inputs and observe the effects immediately.

The first stage of this research was to define the overall need or objective. Previous observations revealed a need to evaluate the benefits and disadvantages of investing in new aircraft capabilities at NASA locations where decisions were often made by a single individual based largely on prior experience, with limited consultation with other stakeholders and insufficient consideration of logistics, staffing, or downstream effects. At Johnson Space Center's Aircraft Operations Division, the need for a model-based decision-support tool remained evident. Although their decision-making involved greater internal coordination, a tool capable of projecting future costs and adjusting customer charge rates could enable the organization to improve safety through aircrew proficiency and maintain continuous, sustained operations.

Other NASA centers have operational structures similar to JSC AOD. Accordingly, a robust and validated AOD model could serve as a template for other NASA flight operations centers. Combining these models could support the creation of a NASA Aircraft Operations Enterprise model and improve budget forecasting and scenario planning at NASA Headquarters.

Recent inflation and fuel price increases further exemplifies the value of a flexible model that allows variables to be modified to examine alternative courses of action. This dissertation therefore presents the baseline design of such a model, analyzes the effects of fuel cost increases, and evaluates options available to the organization to offset those increases. The results and capabilities derived within this paper will allow program managers to project required resources into future years and adjust real-time variables to compensate for real-world dynamic changes to

enable the organization's success. Also, safety managers will be provided additional resources, both financial and process, to analyze, identify, classify and mitigate safety areas of concern.

Therefore, the "Needs Statement" for this dissertation is as follows:

"NASA Aircraft Operations decision-makers require an analytical tool capable of scenario-based, dynamic optimization to enhance budgetary and asset efficiency while supporting the development and implementation of safety mitigation strategies supporting successful maintenance and flight operations."

CHAPTER 2: METHODOLOGY AND BASELINE SYSTEM DYNAMICS MODEL

2.1 VensimPLP® Modeling Methodology

In alignment with the well-defined “Needs Statement” presented in Chapter 1, an extensive review of scholarly literature and professional journals was conducted to identify prior research efforts relevant to the systems engineering analysis developed in this dissertation, with particular emphasis on the application of system dynamics. This review was performed using academic journal databases, library resources, and authoritative textbooks. The literature indicates that while system dynamics has been applied to analyze specific components of aircraft operations, there is limited evidence of its use in modeling the aircraft operations organization at a holistic, Center or NASA Enterprise level [24] [53] [85].

To establish a simplified yet representative architecture of a generic business entity, consultation was conducted with a Certified Public Accountant (CPA) to determine appropriate methodologies for valuing an organization in a real-world context [38]. The resulting framework, though initially qualitative, demonstrated broad applicability across multiple organizational types, including but not limited to aviation enterprises. This conceptual valuation approach was subsequently formalized into a mathematical structure following the development of the organizational architecture using *Equation (1)* as its foundation.

Further refinement of the model was supported by aviation accounting literature, which enabled the classification of organizational costs into two primary categories: fixed costs and variable costs [47] [82]. These sources provided a foundational basis for structuring cost relationships and were integral to both the development of the system architecture and the construction of the baseline system dynamics model.

2.1.1 *Architecture*

Architecture serves as the foundational framework upon which system design and implementation are developed. It provides an organizing structure that governs the composition and interaction of program elements [4] [7]. A well-defined, model-based architecture enables efficient modification of a baseline model to support varying analytical objectives. It also establishes the boundaries of the system and its associated interfaces with external entities.

For this study, a process-based architecture was developed through structured interviews with key stakeholders, including managers, engineers, aircraft program managers, and financial analysts. Given that the primary performance metrics of the model are financially driven, all processes were evaluated in terms of revenue, expenses, and asset value. Each of these primary categories is further decomposed into subordinate levels, including types of revenue streams, expense classifications, and asset categories (Figure 21) [86].

These elements can be directly attributed to specific programs or assets. As illustrated in Figure 21, all aircraft contribute across the full spectrum of revenue generation, cost incurrence, and asset valuation, reinforcing the interconnected nature of the system. From a business process standpoint, Figure 21 can also be used to establish the boundaries of the JSC aircraft operations model which is later used to develop the top-level tier of the system dynamics model.

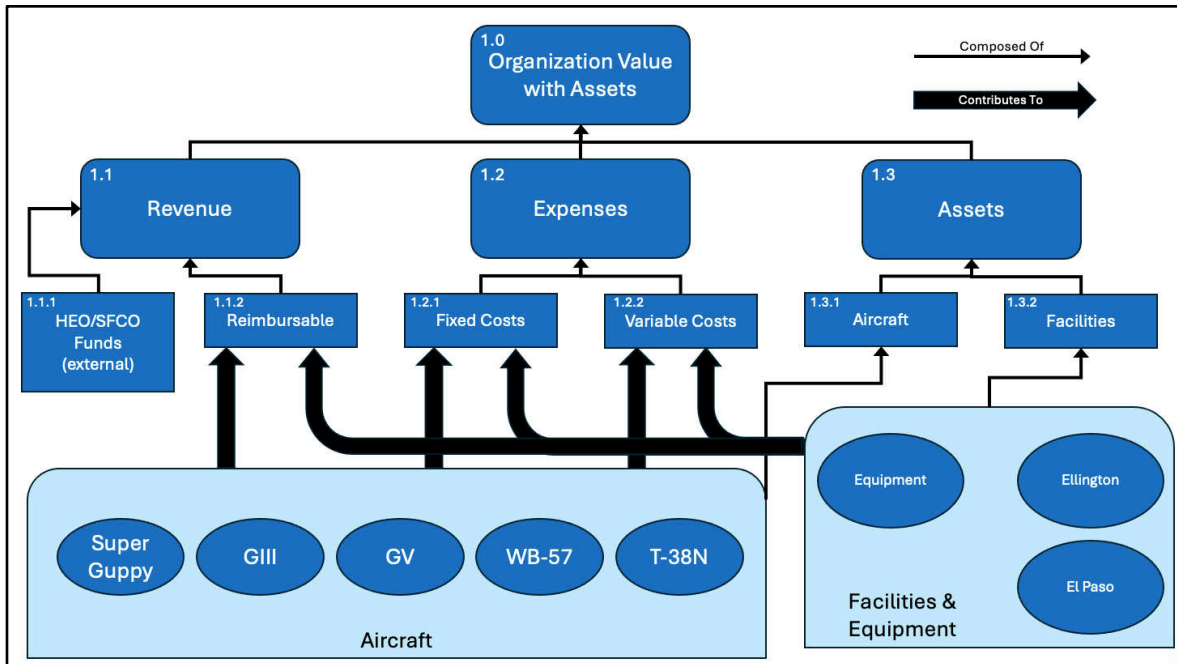


Figure 21. Architecture of NASA JSC Aircraft Operations Using “Top-Down” Tier Flow Diagram

2.1.2 Metric Acquisition

The acquisition of data for model development required a combination of database mining, structured interviews, and targeted surveys. In addition, a forward-looking systems perspective must be applied to identify which variables should remain static and which should be user-adjustable within the model. A recommended approach is to compile a comprehensive list of candidate metrics and designate, via annotation (e.g., asterisking), those parameters intended for manipulation during optimization. *Appendix A* provides a complete listing of these selected metrics, along with the assumptions incorporated into the baseline model.

For the NASA Johnson Space Center (JSC) research study, primary data sources included the NASA Aircraft Management Information System (NAMIS) and associated maintenance software suites. These systems enable detailed extraction of key operational and maintenance metrics, including failure rates, inventory levels, and cost data for both scheduled and

unscheduled maintenance activities across the 26-aircraft fleet. Additionally, operational utilization metrics, such as monthly flight hours per aircraft (Figure 22 and Figure 23) and monthly sortie counts (Figure 24 and Figure 25) were obtained directly from NAMIS.

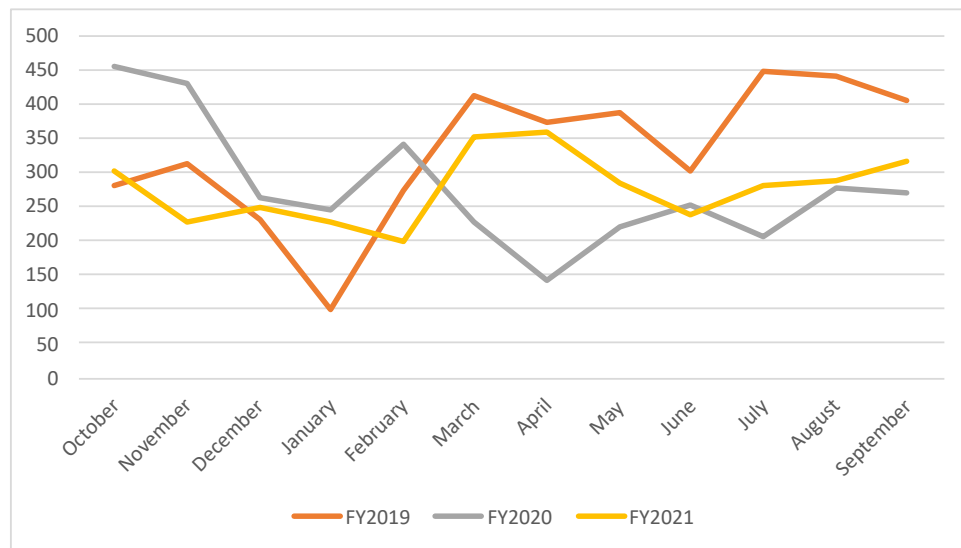


Figure 22. NASA JSC Flight Hour Breakdown (All Aircraft per month; FY2019-FY2021)

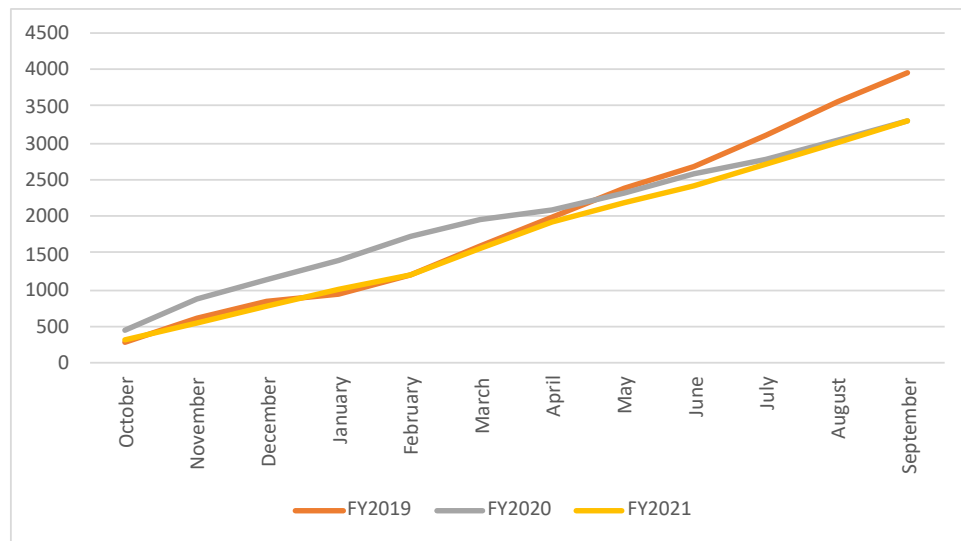


Figure 23. NASA JSC Cumulative Flight Hour Distribution (All Aircraft; FY2019-FY2021)

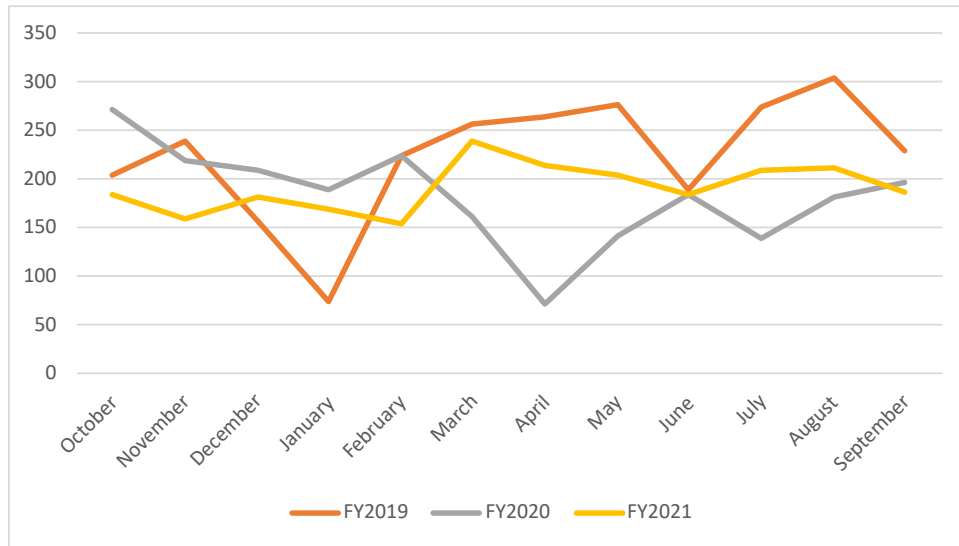


Figure 24. NASA JSC Flight Sorties Breakdown (All Aircraft per month; FY2019-FY2021)

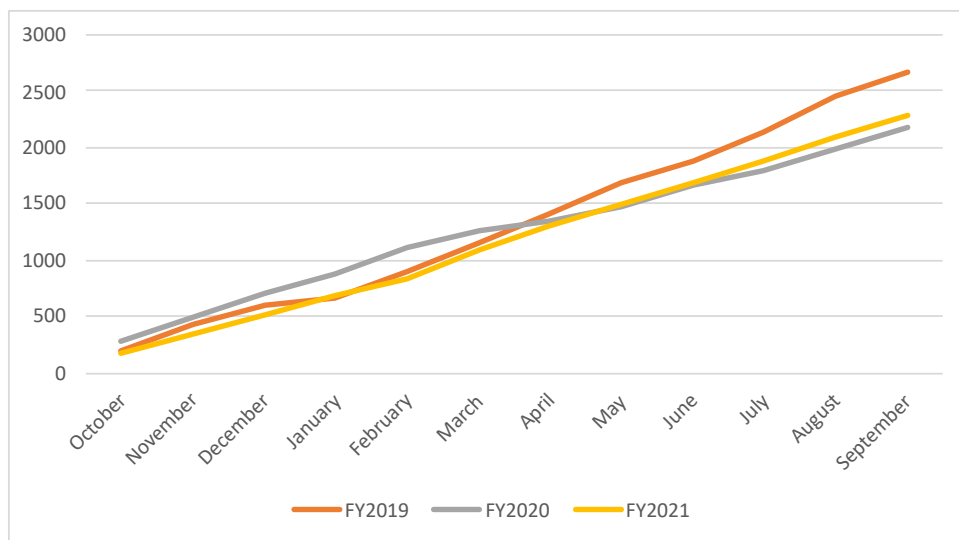


Figure 25. NASA JSC Cumulative Flight Sorties Distribution (All Aircraft; FY2019-FY2021)

Supplementary financial and programmatic data were collected through interviews with program managers. These inputs included data on reimbursable revenue streams, customer billing rates per flight hour for both reimbursable and inter-center agency funding, and budget allocations from the Human Exploration and Operations Mission Directorate (HEOMD) [17]. Together, these data sources provide a comprehensive and validated data source for the system dynamics model.

2.2 Top-Down Model Design

The top-level model applies fundamental economic principles to estimate the “Value” of the aircraft operations organization (Figure 21). This metric was identified as the primary indicator for assessing the organization’s overall performance and long-term viability. For purposes of this research the organization’s Value is defined as:

$$V_{org}(t) = [V_A(t) + V_{Fac}(t)] + V_{SU}(t_0) + \int_{t_0}^t [R(t) - \{C_F(t) + C_V(t)\}]dt \quad (5)$$

Where:

$V_{org}(t)$ = Net Value of an org with assets at a specific time.

$V_A(t)$ = Value of all Operational Assets of the org at a specific time.

$V_{Fac}(t)$ = Value of all Facilities owned by the org at a specific time.

$V_{SU}(t_0)$ = Startup value or investment of
the org at time zero minus assets and facilities.

$R(t)$ = Revenue stream into the org at a specific time.

$C_F(t)$ = Fixed Cost of the org at a specific time.

$C_V(t)$ = Variable Cost of the org at a specific time.

t_0 = Start time of the simulation or time horizon.

t = The specified time contained within the time horizon.

Note: that an organization’s instantaneous profit, $P(t)$, can be modeled by **Equation (6)**

$$P(t) = [R(t) - \{C_F(t) + C_V(t)\}] \quad (6)$$

Note: Operational Assets consist of aircraft, equipment, parts on shelf, etc. that are not real estate related.

In government-operated organizations, management typically aims to achieve a “net-zero” financial position [17] [52]. By the end of the fiscal year, allocated funds are expected to

be fully expended or under contract. Any unexpended funds are either returned or reallocated to programs operating at a deficit. Historically, failure to execute the full budget may negatively impact future funding allocations. In contrast, profit-driven organizations track value as a dynamic financial metric, capturing real-time performance as well as historical trends and future projections [34] [86].

The system dynamics model developed in this research was implemented using VensimPLP®. Within the system dynamics framework, “Value” is represented as a stock variable. In this context, the stock can also be interpreted as “Net Profit,” excluding asset valuation. The primary inflow to this stock is “Revenue,” while the primary outflow is “Expenses.” Both flows are defined in units of U.S. dollars per month (USD/month), consistent with their integration into the stock variable. At a high level, this modeling approach is broadly applicable to a wide range of organizational operations [14] [35].

A top-down modeling methodology with incremental refinement was employed, with the top-level structure illustrated in Figure 26. The baseline model is limited to a maximum of four hierarchical tiers. During the top-down architectural development, decisions must be made regarding which components warrant detailed modeling, which can be reasonably approximated through sensitivity analysis, and which may be omitted without compromising model fidelity. For example, a percentage of the aircraft’s asset value at a specific time was used to approximate the calendar scheduled or fixed maintenance actions. Those actual fixed maintenance costs were used to determine what percentages were to be used in the model as approximations. Finally, asset valuation must be incorporated to provide a comprehensive assessment of the organization’s overall value at any specific time which includes its organizational assets.

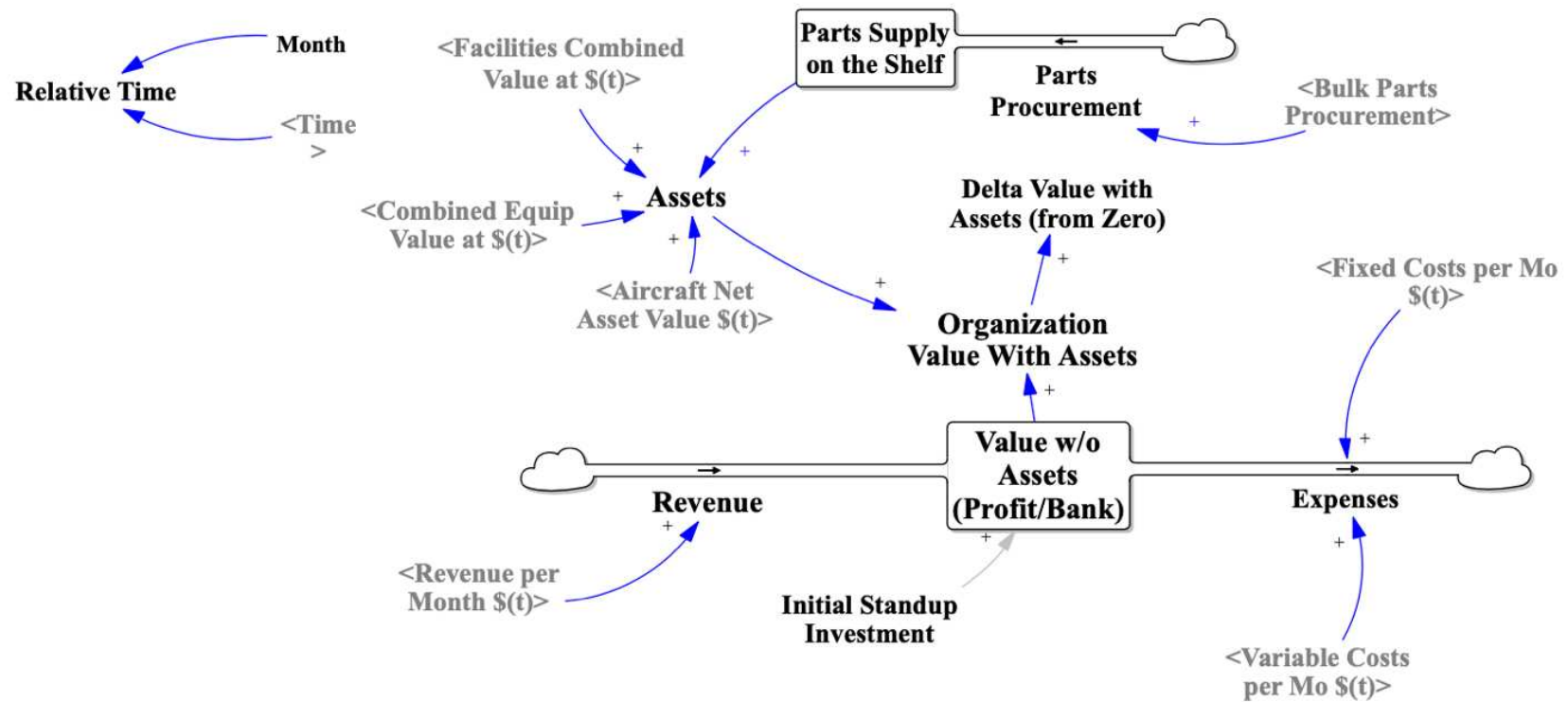


Figure 26. System Dynamics Top-Level Model of NASA Aircraft Operations.

2.3 Valuation of Assets

To determine the total value of an organization, all owned assets must be systematically accounted for. These assets include facilities, aircraft, support equipment, and inventory [47] [85]. Due to their high acquisition and operating costs, aircraft represent a significant financial burden within aviation organizations. Accordingly, depreciation (or devaluation) of these assets must be incorporated as a cost element in any comprehensive financial model [41] [47].

In this model, asset depreciation is represented as a continuous, real-time reduction in value. A commonly accepted approach for estimating asset value over time is the linear depreciation model, also referred to as the straight-line method. This method defines an initial asset value devaluation rate at time $t = 0$, denoted as $V_{A_{t=0}}$, a salvage value V_{A_s} estimated through historical data analysis, and an expected asset lifespan L_A (**Equation (7)**). Therefore, the linear depreciation model approach provides a reasonable approximation for calculating asset values over future time horizons.

$$D_A = \frac{V_{A_{t=0}} - V_{A_s}}{L_A} \quad (7)$$

Where:

D_A = Depreciation Rate of Asset.

$V_{A_{t=0}}$ = Value of Asset at time zero.

V_{A_s} = Salvage Value of the Asset at the end of its life.

L_A = Lifespan duration of the Asset.

Within the system dynamics framework, each aircraft's value is modeled as an individual “stock” (Figure 27). A negative feedback (balancing) loop is implemented to prevent further depreciation once the asset's current value, $V_A(t)$, reaches the salvage value, V_{A_s} . **Equation (8)** applies the linear depreciation methodology to calculate the rate of value reduction and is embedded within the system dynamics model for each asset individually (illustrated for the Gulfstream V in Figure 27).

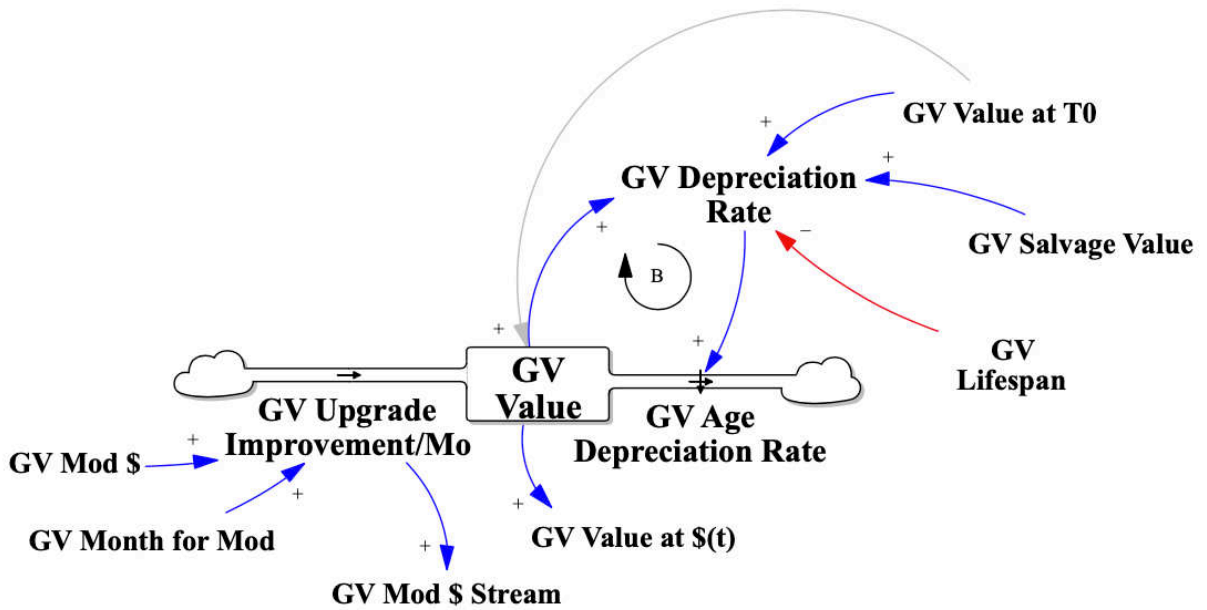


Figure 27. System Dynamics Model of Gulfstream V Aircraft Asset Valuation

$$V_A(t) = V_A(t - 1) + \int_{t=0}^t [V_{A_i}(t) - D_A]dt \quad (8)$$

Where:

$V_A(t)$ = Value of Asset at a specific time.

$V_A(t - 1)$ = Value of Asset at the previous time iteration.

$V_{A_i}(t)$ = Improvement Value of the Asset at the time of improvement.

D_A = Depreciation Rate of the Asset (**Equation (7)**)

t = The specified time contained within the time horizon.

Aircraft valuation may also be influenced by capital improvements. Upgrades can increase an aircraft's value; however, these enhancements require financial investment. Funding for such upgrades may originate from internal reserves, external financing, or allocated operational budgets.

A similar valuation framework is applied to facilities. While land and property may appreciate over time, physical infrastructure typically depreciates. The net facility value is therefore dependent on the relative sensitivity of these opposing valuation trends and may result in either a net increase or decrease in overall value.

To illustrate the effect of asset depreciation, the Gulfstream V asset value, referenced in Figure 27, is modeled and plotted over a 36-month time horizon as shown in Figure 28. In this case, the initial asset value at $t=0$ is \$17.0M USD, with a salvage value of \$1.5M USD and an assumed operational lifespan of 25 years (300 months). These parameters define the linear depreciation (devaluation) rate of the aircraft, calculated as \$51,667 USD-per-month. Within the system dynamics framework, this depreciation rate represents an outflow from the "GV Value" stock.

Conversely, inflows to the "GV Value" stock consist of capital investments such as modifications, system upgrades, and performance enhancements. These inputs effectively re-baseline the aircraft's value at discrete points in time, reflecting improvements in capability and operational utility.

Figure 28 illustrates the asset value trajectory over the initial 36 months. In the modeled scenario, the Gulfstream V undergoes a \$1.7M USD avionics/display upgrade beginning in month 2. This analysis assumes a one-to-one cost-to-value relationship; therefore, the \$1.7M

USD investment directly increases the aircraft's asset value by an equivalent amount. This investment represents a fixed cost required to sustain and enhance operational capability.

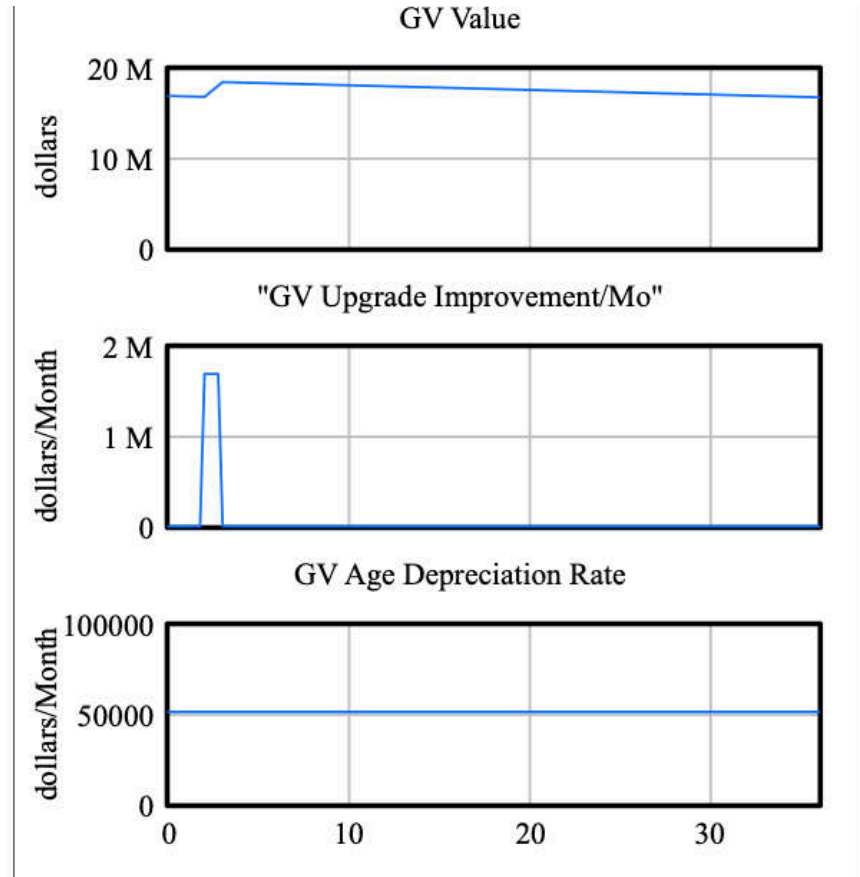


Figure 28. System Dynamics Output of Gulfstream V Aircraft Asset Valuation Over Time (36 Months)

The aggregate “Aircraft Net Asset Value” is computed as the sum of all individual aircraft asset values within the organization. Figure 29 presents the total fleet asset value at NASA Johnson Space Center (JSC) over the same 36-month horizon. The fleet composition includes 20 T-38N aircraft [75], 3 WB-57 aircraft [73], 1 Gulfstream V [67], 1 Gulfstream III [69], and 1 Super Guppy [71]. Observed increases in total asset value are driven by cumulative upgrade investments across the fleet, with the most significant contributions attributable to the T-38N platform due to its quantity within the inventory.

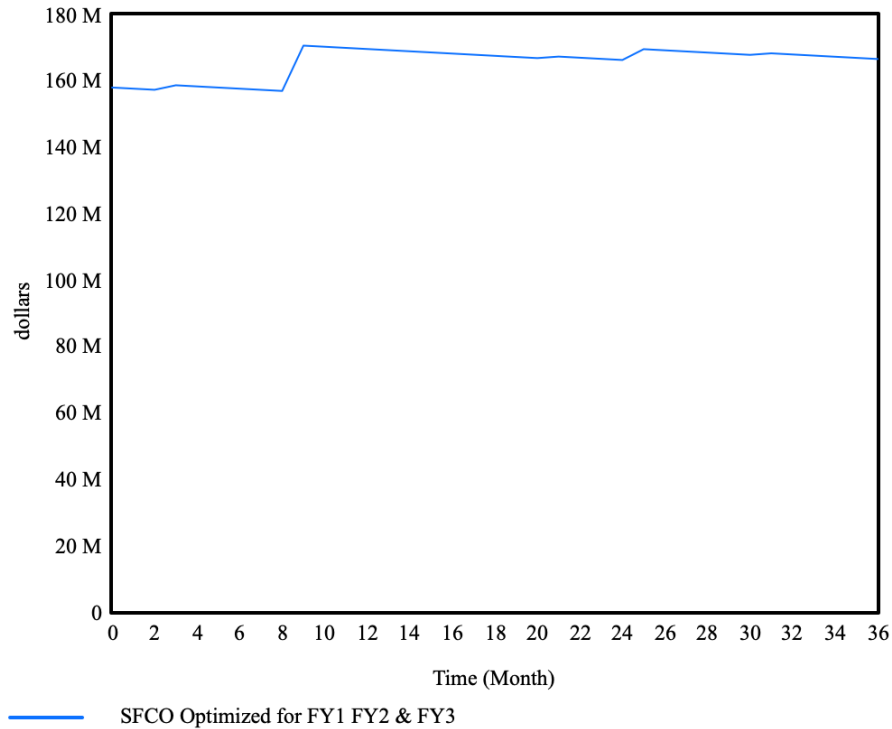


Figure 29. System Dynamics Output of ALL Aircraft Asset Valuations Combined Over Time (36 Months)

2.3.1 Fixed Cost Determination

The outflow from the “Value” stock is represented by “Expenses” (Figure 26). Expenses are categorized into two primary types: fixed costs and variable costs [47]. Fixed costs represent the baseline expenditures required to sustain organizational operations, even in the absence of active flight operations. These include rent or mortgage obligations, baseline personnel salaries, essential utilities (e.g., electrical power and sewage), applicable taxes, aircrew training, and scheduled aircraft maintenance (Figure 30).

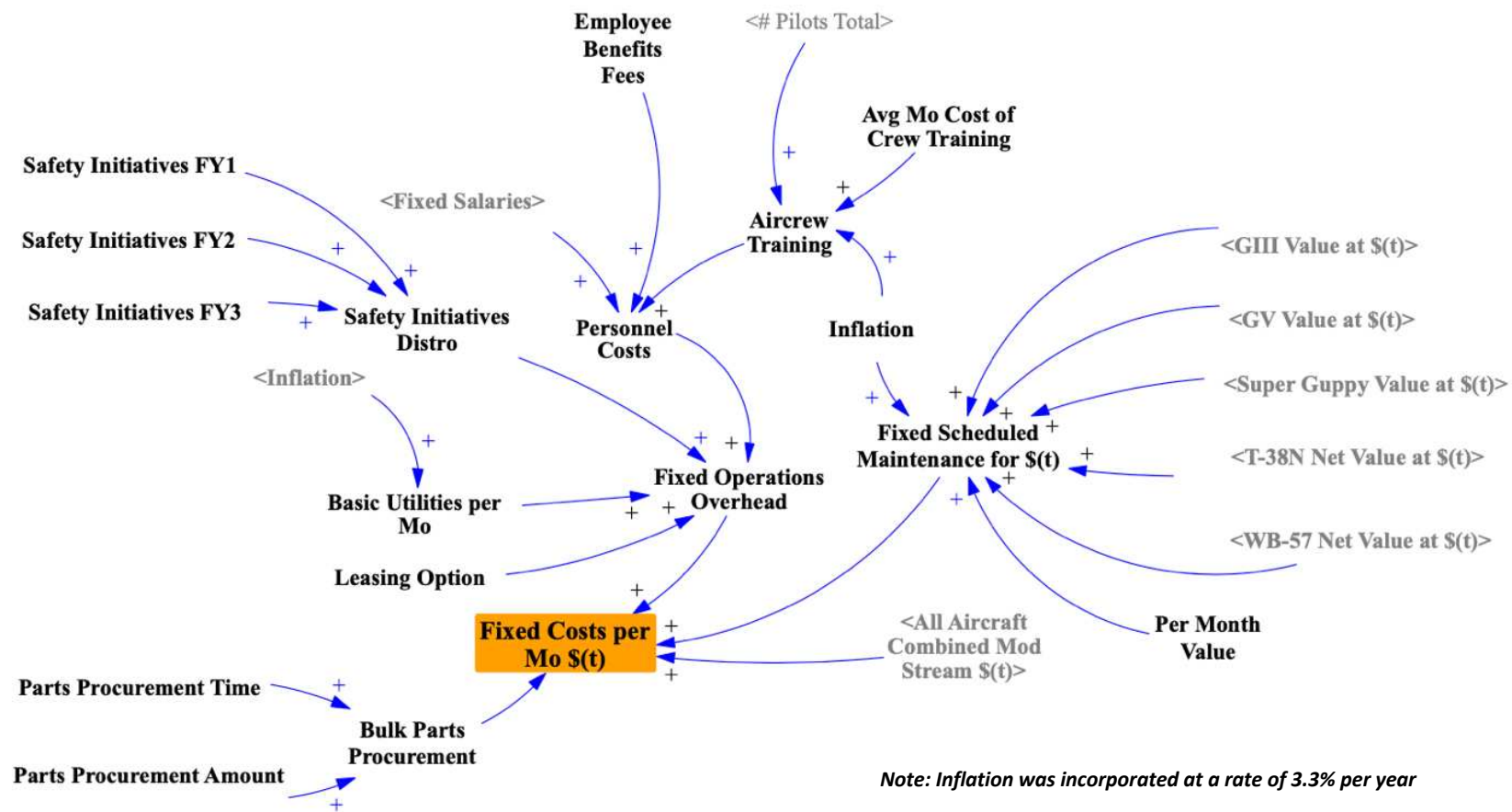


Figure 30. System Dynamics Model of NASA JSC Aircraft Operations Fixed Cost

Maintenance activities constitute a critical component of sustained aircraft operational capability. For “Fixed Scheduled Maintenance,” a percentage of each aircraft’s “Net Value” is used to approximate the cost of calendar-based phased maintenance. This estimation is derived from historical maintenance data and provides a reasonable approximation of recurring maintenance requirements. While this approach simplifies the model, it ensures that mandatory maintenance actions, independent of flight activity, are consistently represented across the simulation time horizon.

Aircraft and equipment leasing are also classified as fixed costs. These may include long-term lease agreements or contingency-based (“on-call”) leasing arrangements. The two principal lease classifications are operating leases and capital leases [82]. Although most aircraft within NASA are owned outright, there are instances in which external organizations are contracted to perform specific mission requirements [16].

Aircrew training and personnel salaries are significant contributors to total fixed costs. Annual training costs for aircrew can reach up to \$60,000 USD per individual, depending on the number of aircraft qualifications maintained. For this study, historical data were utilized to estimate average monthly training expenditures. While the baseline model assumes a constant number of aircrew, increases in operational demand necessitate proportional increases in personnel, training requirements, and associated costs. Additionally, there may exist a “qualification/experience lag” of approximately 1–2 years before aircrew are fully mission-capable for certain types of NASA flight operations.

Personnel salaries typically represent the largest cost category within an organization [47]. Achieving an optimal compensation structure is essential to balance workforce retention and cost efficiency. This model incorporates separate average hourly wage rates for Government

Civil Service (GS) personnel, Contractor Service (CS) employees, and pilots. These rates were calculated using historical NASA human resources data. This assumption streamlines the model by avoiding the complexity associated with a wide distribution of specialized pay scales.

However, the system dynamics framework is inherently extensible; if higher fidelity is required, additional sub-models can be introduced to represent more precise salary distributions across specific occupational specialties.

2.3.2 Variable Cost Determination

Variable costs represent the class of expenditures that scale directly with operational activity (Figure 31). Within the context of aircraft operations, these costs can be interpreted as the resources required to execute mission-specific flight operations. A primary example is aviation fuel consumption [47]. Fuel cost is a direct function of flight hours; when operations cease, fuel expenditures are effectively reduced to almost zero. Conversely, when operations resume, fuel becomes a dominant variable cost component. Fuel-burn rates vary significantly by aircraft type, typically ranging from approximately 300 to 1,000 U.S. gallons per flight hour per aircraft per each aircraft's flight manual performance charts.

In addition to fuel, both unscheduled maintenance and flight-hour-driven phased maintenance contribute to variable costs. While increased utilization may, in some cases, improve system reliability due to operational consistency, all aircraft will inevitably incur unscheduled maintenance over time. Furthermore, consumables such as oil, hydraulic fluid, oxygen, nitrogen, and other Petroleum, Oil, and Lubricants (POL) are expended during routine preflight, post-flight, and corrective maintenance activities [82]. The cost associated with these items is directly proportional to aircraft usage.

Note: Inflation was incorporated at a rate of 3.3% per year

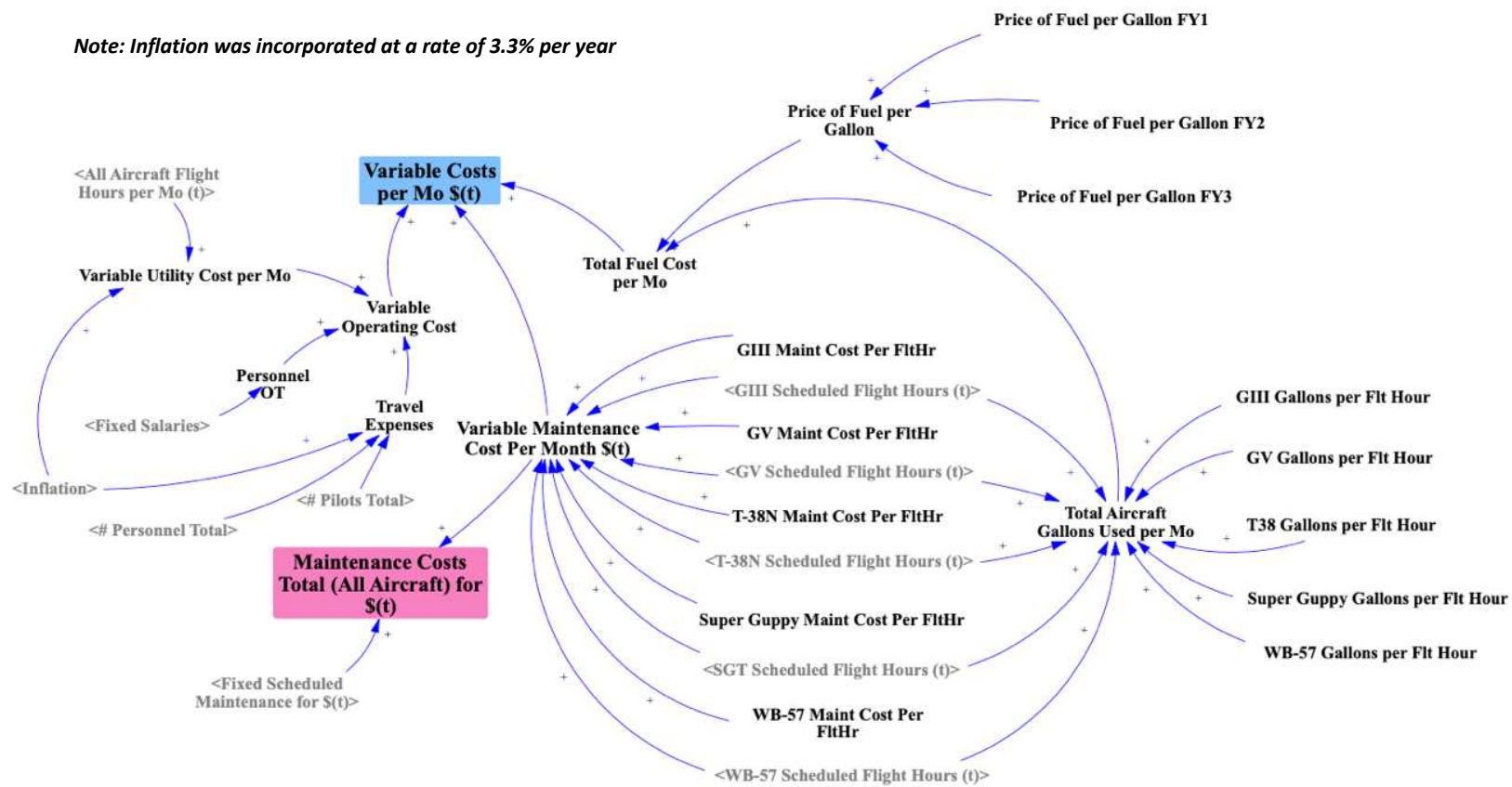


Figure 31. System Dynamics Model of NASA JSC Aircraft Operations Variable Cost

The primary driver of variable cost is total flight hours accumulated per aircraft. Maintenance cost per flight hour is typically represented as an averaged value derived from analyses conducted by Reliability, Maintainability, and Availability (RM&A) specialists in coordination with Maintenance Program Managers. This averaged metric enables consistent modeling of maintenance-related expenditures within system dynamics frameworks.

Travel-related expenses are also categorized as variable costs. Missions executed away from the primary operating base necessitate additional expenditures for personnel travel, lodging, and logistical support. As with other variable costs, these expenses are incurred only when mission activity is conducted.

In summary, any cost that scales with operational tempo, specifically flight activity, should be classified as a variable cost. If operational activity is reduced or suspended, these costs decrease accordingly. Conversely, costs that persist independent of operational status should be classified as fixed costs.

2.3.3 Revenue Determination

“Revenue” constitutes the primary inflow to the “Value” stock (Figure 26; [43]) and is derived from multiple funding streams depending on the organizational structure. For government entities, budget allocations established through the Planning, Programming, Budgeting, and Execution (PPBE) process represent the principal source of funding [17]. In contrast, profit-driven organizations primarily generate revenue through customer payments for services rendered.

Within the NASA system dynamics model, the primary customer-based revenue streams are “SFCO/HEO Annual Funding” (Figure 32) and “Reimbursable Funding” (Figure 33). At

NASA Johnson Space Center (JSC), SFCO funding is allocated annually through the PPBE process and is largely driven by projected T-38N flight hours for future fiscal years. These projections are based on anticipated mission requirements and the number of aircrew requiring training. Additional funding may be received in the form of supplemental contributions from higher-level organizations or external sources. Such funds are typically non-contractual and are intended to enhance operational capability; for example, through the acquisition of additional aircraft or the implementation of science modifications and upgrades via the Airborne Science Program (ASP) to expand mission capability and attract new customers.

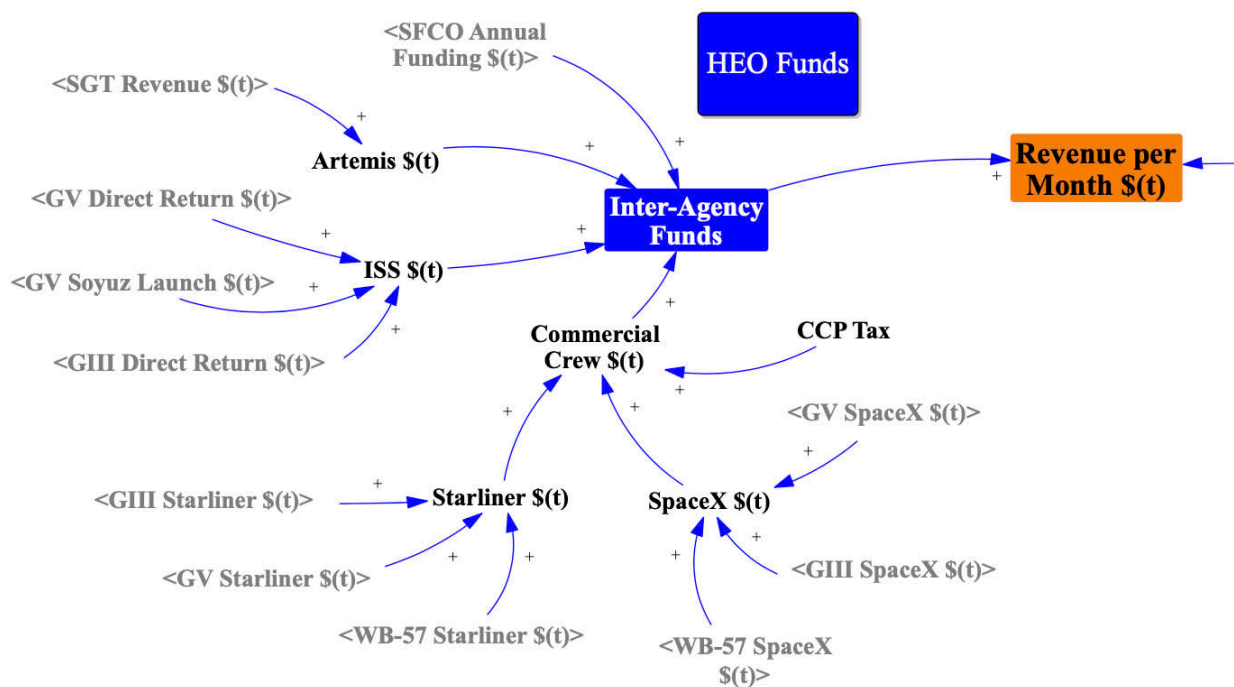


Figure 32. System Dynamics Model of NASA JSC Aircraft Operations Revenue (HEO)

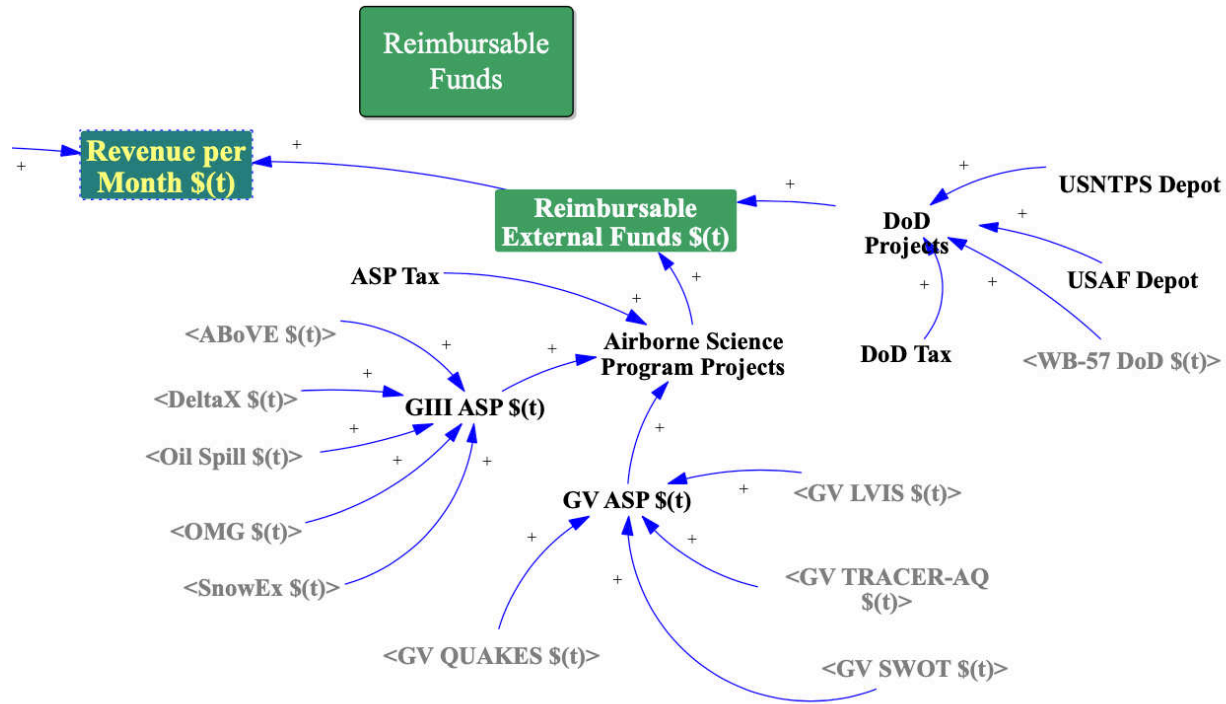


Figure 33. System Dynamics Model of NASA JSC Aircraft Operations Revenue (Reimbursable)

Revenue generation at the aircraft platform level is highly granular and requires detailed analysis. Figure 34 illustrates a representative revenue tier model for the Gulfstream V, derived from actual mission flight hours. Comparable revenue tier structures exist for other aircraft; however, each platform supports unique, mission-specific capabilities that must be independently evaluated when determining total organizational revenue. For instance, the Super Guppy Transport aircraft is utilized for large-scale cargo transport, such as spacecraft components, whereas the WB-57 aircraft supports launch and reentry surveillance missions. These capabilities are not interchangeable and are funded through distinct mechanisms.

Customer charges are determined by each aircraft program's Program Manager and are based on the total level of effort required to integrate, test, and execute the mission. The resulting "charge per flight hour" is typically derived from historical fixed and variable cost data associated with comparable missions. For maintenance-related activities, such as depot-level

maintenance, cost estimation is based on projected maintenance man-hour requirements. All services are formalized through contracts or interagency agreements that specify scope, deliverables, and associated fees.

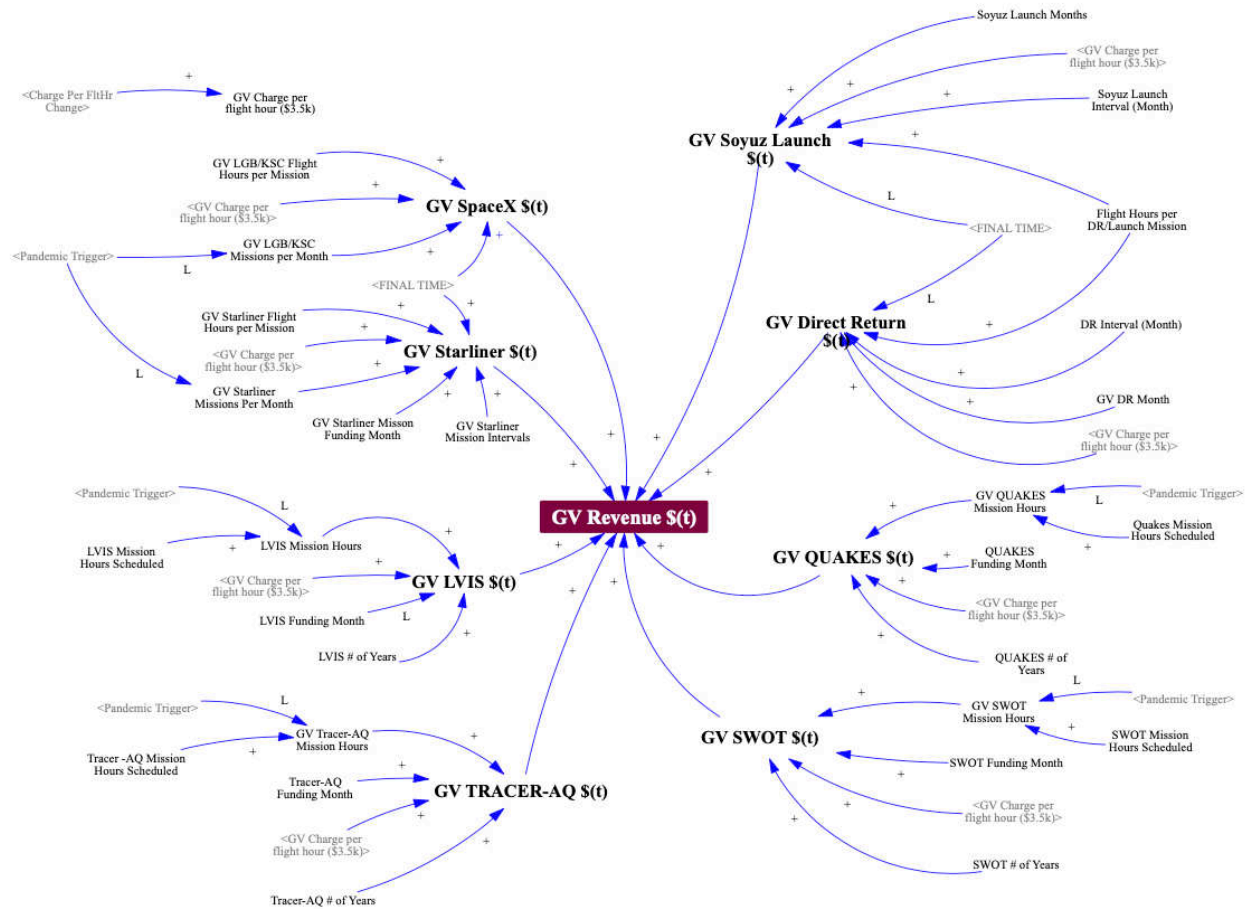


Figure 34. System Dynamics Model of NASA JSC's Gulfstream V Revenue

2.3.4 Dashboard Panel

VensimPLP® provides a unique capability through its SyntheSim function, which enables users to modify model variables either individually or concurrently while observing system responses in real time. To facilitate an integrated and intuitive user interface, a consolidated “Dashboard Panel” (Figure 35) was developed to serve as a centralized control environment for scenario analysis.

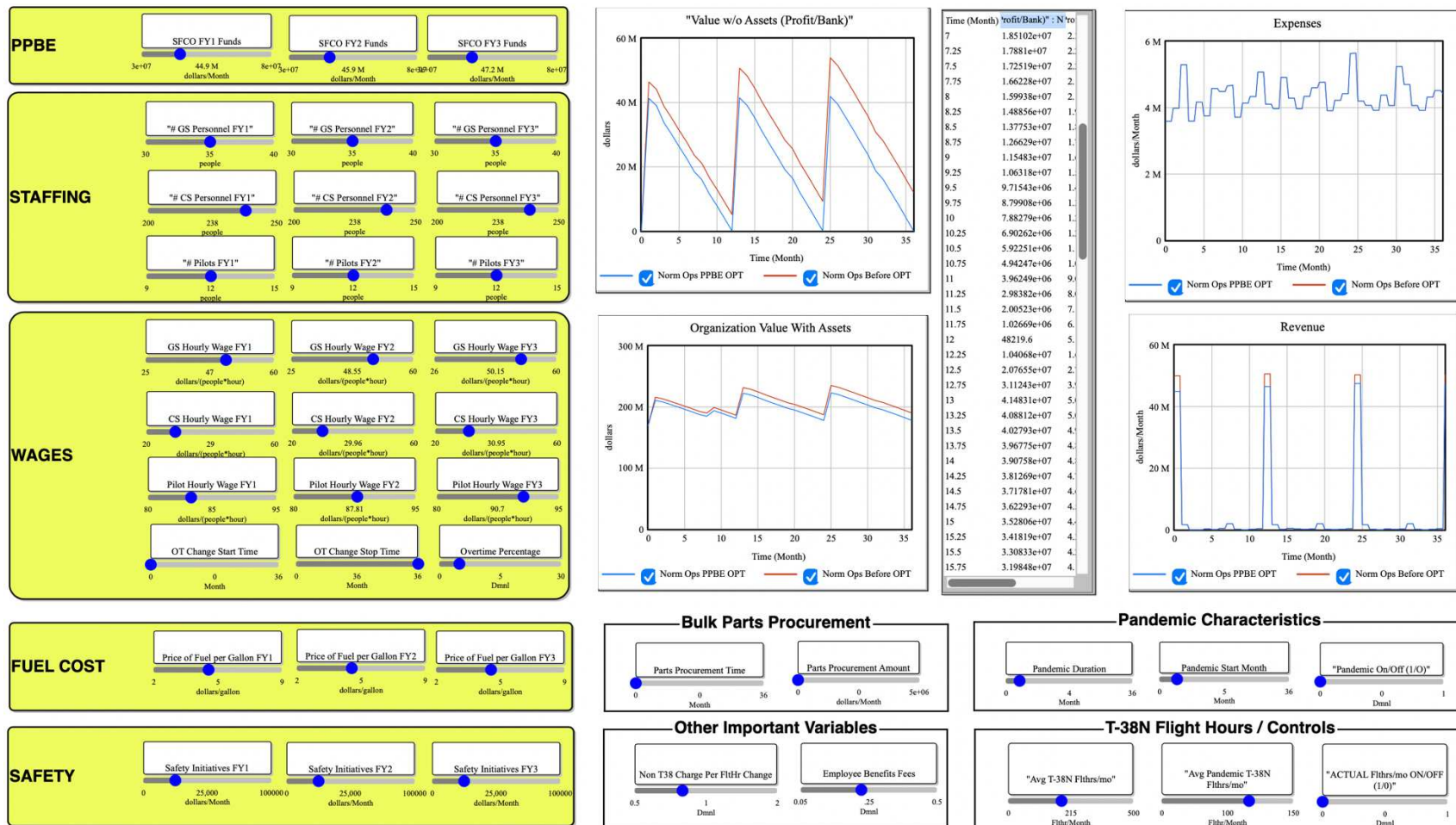


Figure 35. System Dynamics Dashboard of NASA JSC Aircraft Operations Baseline Model Dashboard

The Dashboard Panel allows users to adjust selected input variables via interactive slidebars (see Figure 35). When SyntheSim is active, these adjustments immediately propagate through the model, enabling dynamic visualization of system behavior across the defined time horizon. This real-time feedback mechanism supports rapid exploration of cause-and-effect relationships and enhances the user's ability to assess system sensitivities.

From a Human Systems Integration (HSI) perspective, the Dashboard Panel improves decision-making efficiency by allowing users to simultaneously evaluate multiple competing variables. This capability supports the optimization of both financial performance and mission objectives by enabling informed trade-off analyses within a single, interactive environment.

2.4 Assumptions Implemented in the System Dynamics Model

Comprehensive documentation of the system dynamics model is essential to ensure transparency and facilitate reproducibility. Clearly articulating the assumptions underlying the model enables other researchers and practitioners to understand the rationale behind the operational structure and simulation behavior. *Appendix A* provides a detailed account of most assumptions incorporated into the model, along with the baseline metric values utilized in its development. In addition, inflation and Cost-of-Living Adjustments (COLA) were incorporated to more accurately represent the changing economic environment over the simulation period. An average of 3.3 percent was applied to each fiscal year, reflecting historical economic trends and, therefore, improving the fidelity and realism of the model when evaluating across multiple years.

2.5 Validation/Verification of the Baseline Model

Establishing an accurate baseline model of current aircraft operations is critical for evaluating the implications of proposed changes. Accordingly, rigorous validation and

verification processes were conducted to ensure the model's fidelity, using historical reference modes as benchmarks [3] [10]. To perform this validation, this research has led a set of Delphi committees to evaluate and assert face validation and sensitivity-analysis-based validation of the model.

The initial Delphi Committee was convened following the construction of the baseline model to assess the realism of its architecture and foundational structure. Key stakeholders participated to verify that their respective operational domains were represented accurately. Collaborative discussions were conducted to identify model deficiencies and implement necessary refinements. Additionally, stakeholder input was incorporated to enhance usability and encourage future adoption of the model as a decision-support tool. See *Appendix D* for details of the Delphi Committees.

A second Delphi Committee was conducted after the simulation results were generated to validate both the model and its outputs. As listed in *Appendix D*, stakeholders that manage the specific programs were queried and discussed the findings. In addition to, the specific aircraft program managers performed a thorough review of the data to verify that the results were sufficiently accurate. These checks and balances ensured that the model exhibits predictive reliability and can effectively support the analysis of potential future scenarios [20].

During the final stages of this dissertation, a third Delphi Committee was convened to provide stakeholders with the most current version of the system dynamics model and to solicit input regarding future requirements for follow-on model variations. Program managers agreed that the model is useful and effective for long-term financial forecasting. Additionally, stakeholders expressed a desire for a capability to track carryover funds and remaining balances into subsequent fiscal years.

Annual reports were also used to validate model outputs by comparing projected expenses and budget forecasts with actual operational data from subsequent fiscal years. For example, the average flight hours forecasted in the FY20 Annual Report [87] closely aligned with the flight hours projected in the baseline model during its third fiscal year (FY3). A comparison of these values revealed a variance of only 1.4%, demonstrating strong agreement between the model’s projections and actual organizational planning data.

2.5.1 Baseline Model Functionality

The model evolved throughout the years of development in response to current events and continuous refinements informed by input from the Delphi Committees. The model’s functionality is primarily based on *Equation (5)* and utilizes a dashboard as its principal user interface. The dashboard was designed to accommodate a wide range of operational scenarios and budgetary strategies. However, certain scenarios may require modifications to the model’s underlying code if they cannot be adjusted directly through the dashboard interface. For example, if the flight hours associated with an individual Airborne Science Mission were to change, the user could access the “Revenue” layer of the model and modify the specific mission parameters accordingly (Figure 36).

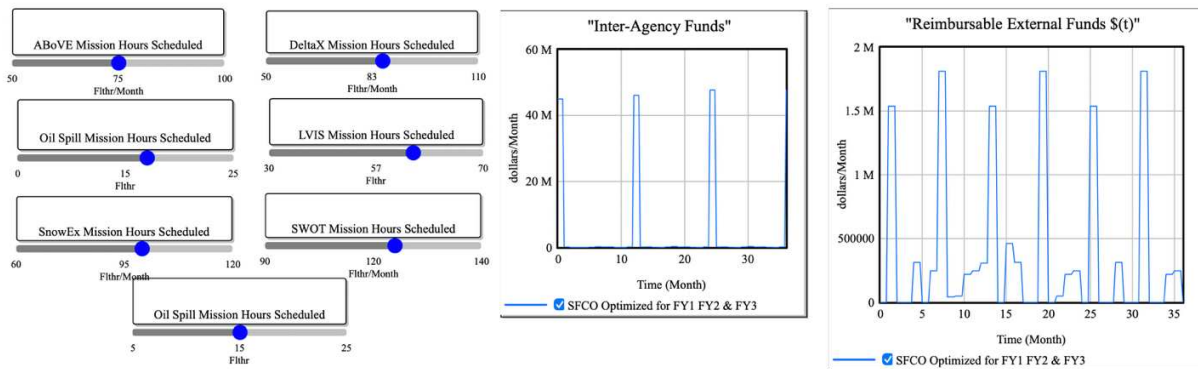


Figure 36. System Dynamics Model’s “Revenue” Layer’s Airborne Science Mission Metrics

Tabular input data can also be modified to accommodate updated metrics. In the baseline model, metrics obtained through research and collected from NAMIS were incorporated as tabular inputs. One example is the actual monthly flight hours flown by T-38N aircraft. Within the baseline model, users may select either the actual flight hours flown, displayed on the main dashboard, or an average monthly flight-hour value by fiscal year, which is captured on the dashboard under “Expenses” (Figure 37). For actual flight-hour utilization, tabular data were extracted directly from NAMIS. Alternatively, when average flight hours are applied, the model produces a smoother distribution of operational activity; however, the resulting outcomes remain consistent because the total number of flight hours utilized within that fiscal year is unchanged (Figure 38).

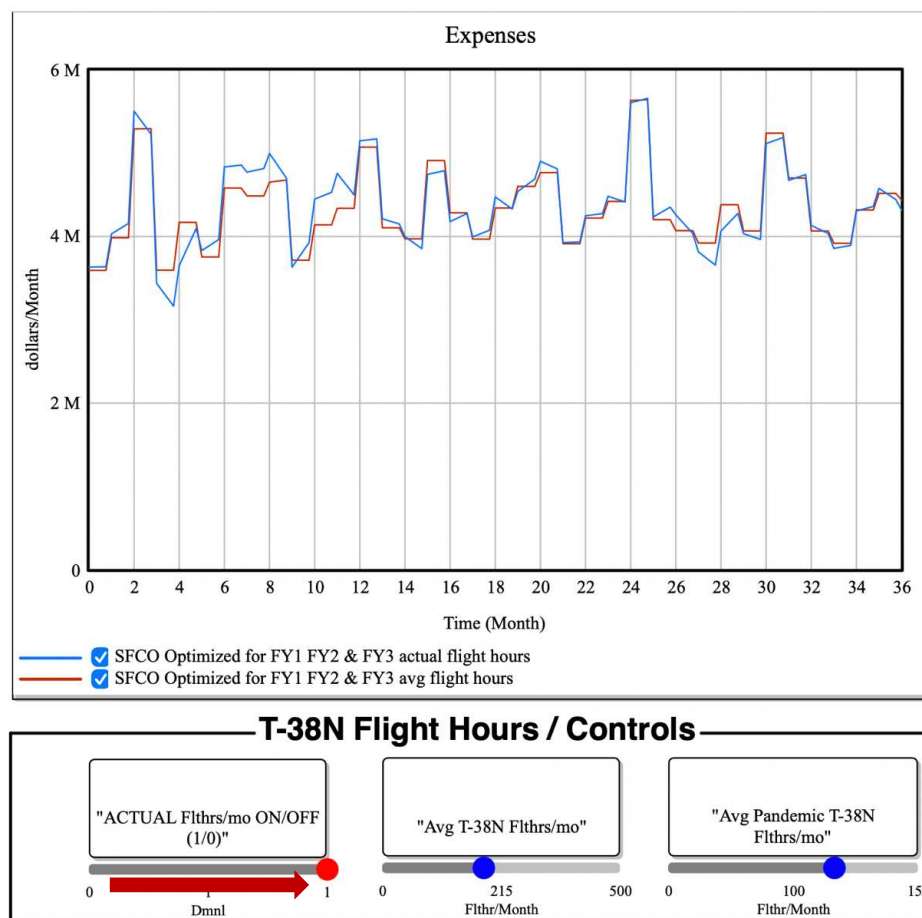


Figure 37. System Dynamics Dashboard Actual vs Average Flight Hours and Its Effect on Expenses

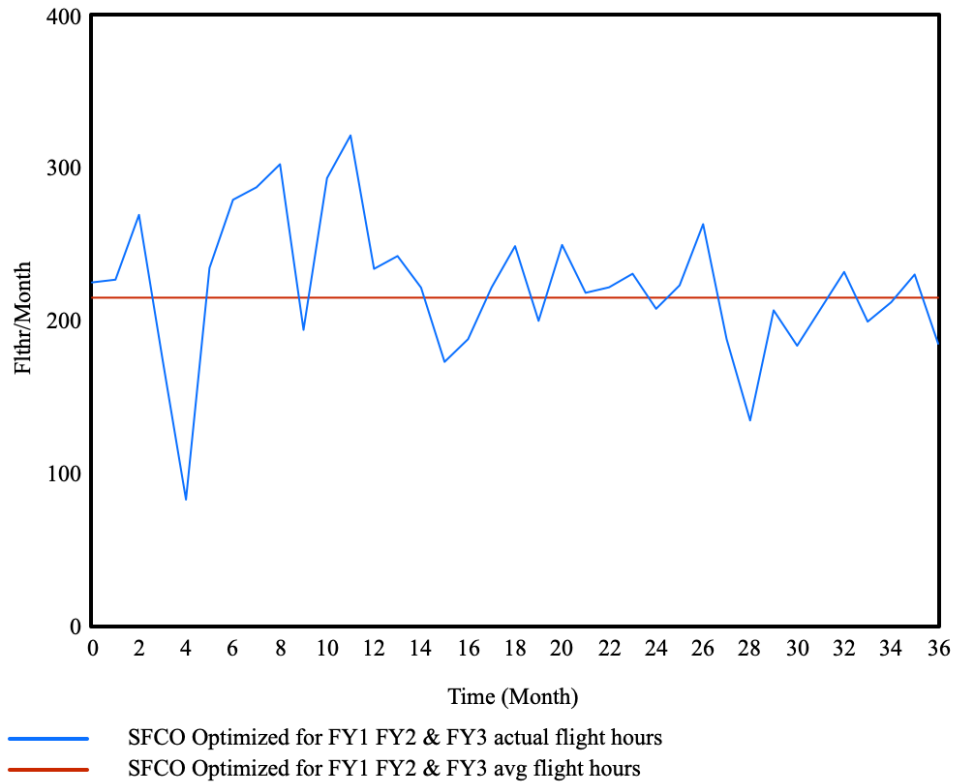


Figure 38. Actual vs Average T-38N Flight Hours

2.5.2 Optimizing the Baseline Model

1) *Scenario 1: Optimizing the Baseline Model by Projecting FY1, FY2, and FY3 SFCO Funds*

The primary financial objective of a government aircraft operations organization is to achieve a net-zero budget balance at the conclusion of each fiscal year. At the beginning of the fiscal year, funds are allocated to the organization and scheduled for expenditure over the subsequent 12-month period. To initialize the model, a representative funding value was required. Accordingly, an estimated funding level of \$55M USD was entered for each of the three fiscal years to initiate the SyntheSim function within the system dynamics model.

The initial results, shown in Figure 39, indicate an upward trend, suggesting the presence of excess funds at the conclusion of each fiscal year that must be reduced to achieve a balanced

budget. Because fiscal-year outcomes influence subsequent years, optimization must be conducted chronologically, progressing from the earliest fiscal year to the latest while targeting the year-end balance of the fiscal year under adjustment.

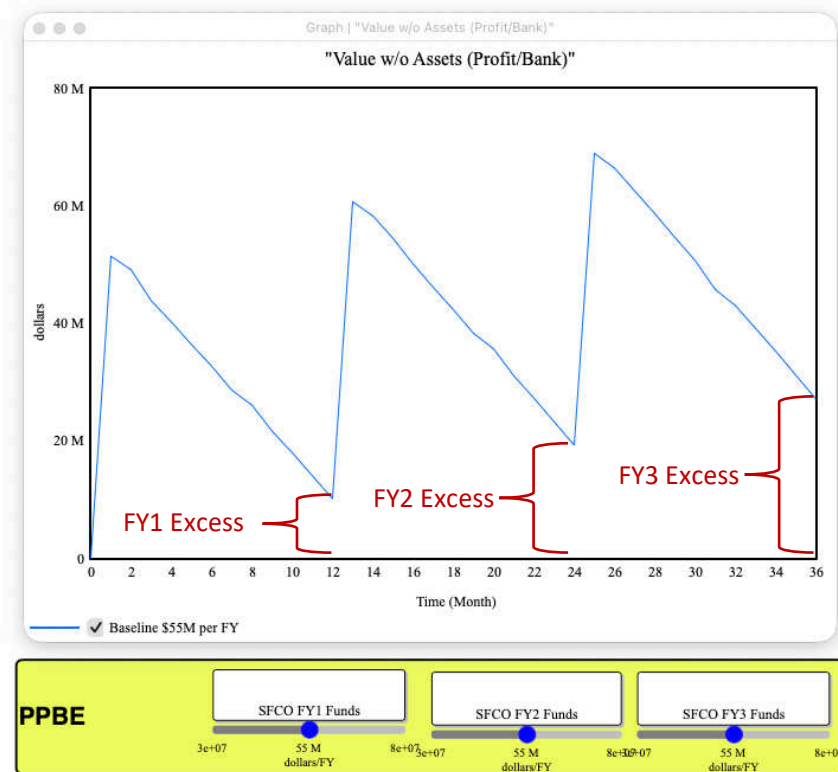


Figure 39. System Dynamics NASA JSC Aircraft Operations Dashboard Pre-Optimization

As illustrated in the “PPBE” section of Figure 35, the FY1 SFCO slider can be adjusted iteratively until the balance at Month 12 reaches zero or remains slightly positive. Using the vertical table within the dashboard, a relatively precise near-zero balance at the end of the fiscal year can be achieved. Figure 40 illustrates the optimized results after balancing the 12th, 24th, and 36th months to near-zero values. Following optimization, the required SFCO funding levels for FY1, FY2, and FY3 were determined to be \$45.0M, \$45.8M, and \$47.4M USD, respectively. The resulting output provides a forecasted three-year programming schedule to support continued Space Flight Readiness Training operations at the Johnson Space Center.

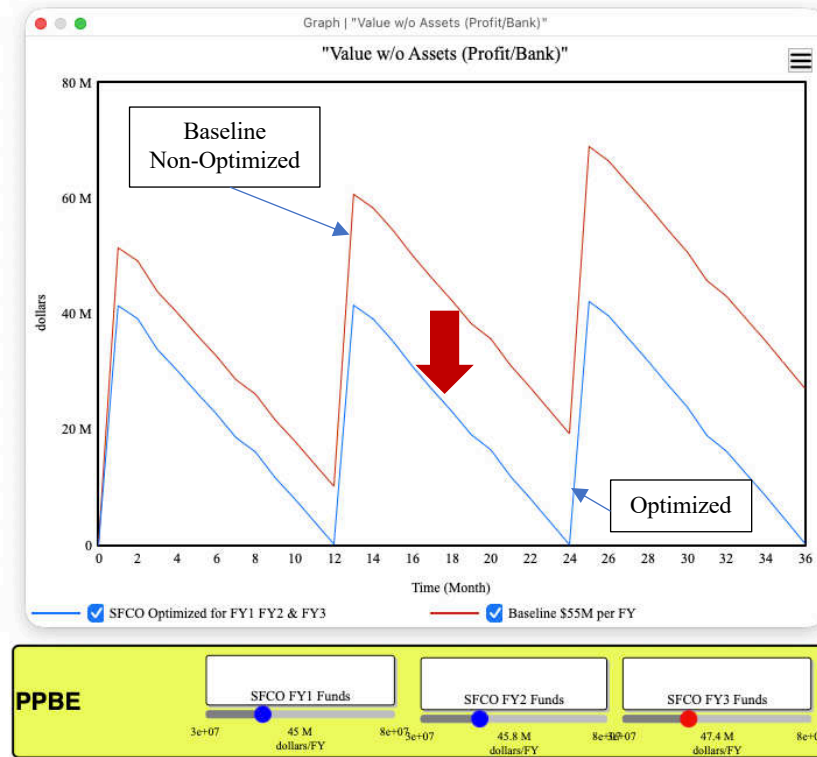


Figure 40. System Dynamics PPBE Optimized for FY1, FY2, and FY3

2) *Scenario 2: Organization Effects of Increase in Fuel Cost (\$5 USD-per-gallon to \$6 USD-per-gallon)*

Global economic inflation has risen substantially in recent months, reaching levels comparable to 40-year highs [21]. Correspondingly, jet fuel prices have experienced significant increases. Building upon the optimized configuration established in Scenario 1, the model was adjusted to evaluate the organizational impact of an increase in jet fuel costs from \$5 USD-per-gallon to \$6 USD-per-gallon, representing a \$1 USD-per-gallon increase. This adjustment was implemented using the dashboard sidebar control (Figure 41).

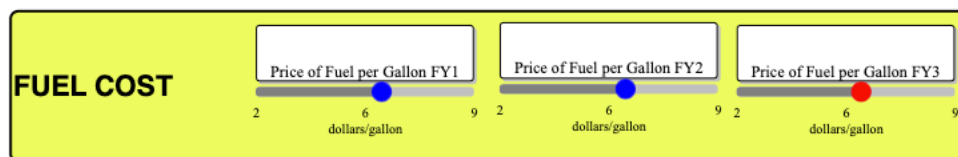


Figure 41. Fuel Cost Sidebar Set to \$6 USD-per-Gallon for FY1, FY2, and FY3

Figure 42 illustrates the resulting system response to the increase in fuel pricing. By the 13th month, corresponding to the conclusion of the first fiscal year, the model projects a deficit of approximately \$1.27M USD at the end of FY1, \$2.01M USD at the end of FY2, and \$4.29M USD at the end of FY3. These additional costs must be offset through alternative measures, such as increasing customer charges, allocating supplemental funding from headquarters, reducing staffing levels, adjusting employee compensation, decreasing flight hours, or any combination thereof. **The dashboard provides the capability to adjust these variables to re-optimize the organization following the increase in fuel costs in a matter of seconds.** As previously discussed, fuel cost represents a dominant variable within the system, and organizational value demonstrates a high degree of sensitivity to fluctuations in this parameter.

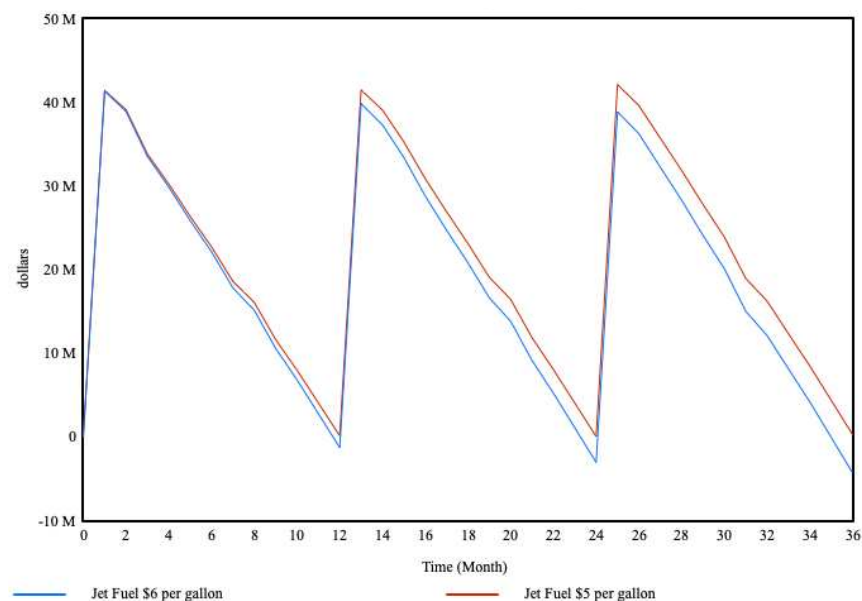


Figure 42. NASA JSC Aircraft Operations Effects of Inflation Model Dashboard, Increased Fuel Cost (\$5 USD to \$6 USD-per-Gallon)

To mitigate the adverse financial impact, additional optimization may be performed using the model's adjustable parameters (e.g., sidebar controls) to rebalance system variables and achieve a net-zero financial outcome by the end of the 12th, 24th, and 36th months.

3) *Scenario 3: Optimization of Budget Deficit Under Increased Fuel Cost Conditions Through Customer Charge Adjustments*

To mitigate the financial impact of increased fuel costs, organizations must either increase revenue or reduce operational expenses. In this scenario, optimization is achieved through a revenue-adjustment strategy by increasing charges to non-T-38N customers, including Gulfstream, WB-57, and Super Guppy Transport aircraft operations. Figure 43 illustrates the optimization results associated with this approach. This method represents a cost-transfer mitigation strategy in which the increased fuel expense is passed directly to the customer.

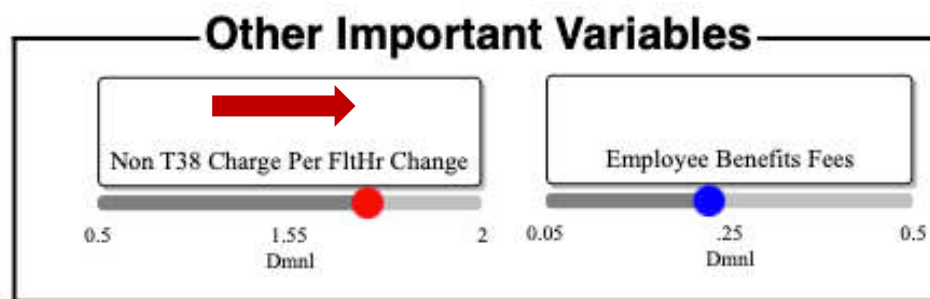


Figure 43. NASA JSC Aircraft Operations Optimized Model Dashboard, Increase in Charge to Customer (1.00X to 1.55X)

Using the “Non-T38 Charge Per FltHr Change” control parameter, the model enables users to iteratively adjust customer pricing to achieve a net-zero financial condition by the end of months 12, 24, and 36. Simulation results indicate that the optimal adjustment corresponds to a 1.55× increase in the customer charge rate. For example, if the baseline rate is \$1,000 USD-per-flight hour, the optimized rate required to achieve budget neutrality by the end of Month 12 is \$1,550 USD-per-flight hour, representing an increase of \$550 USD-per-flight hour to offset the rise in fuel costs.

A higher-resolution view of “Value without Assets” is provided in Figure 44. When the charge rate is optimized, the resulting value profile overlays the optimized organizational value across all three fiscal years.

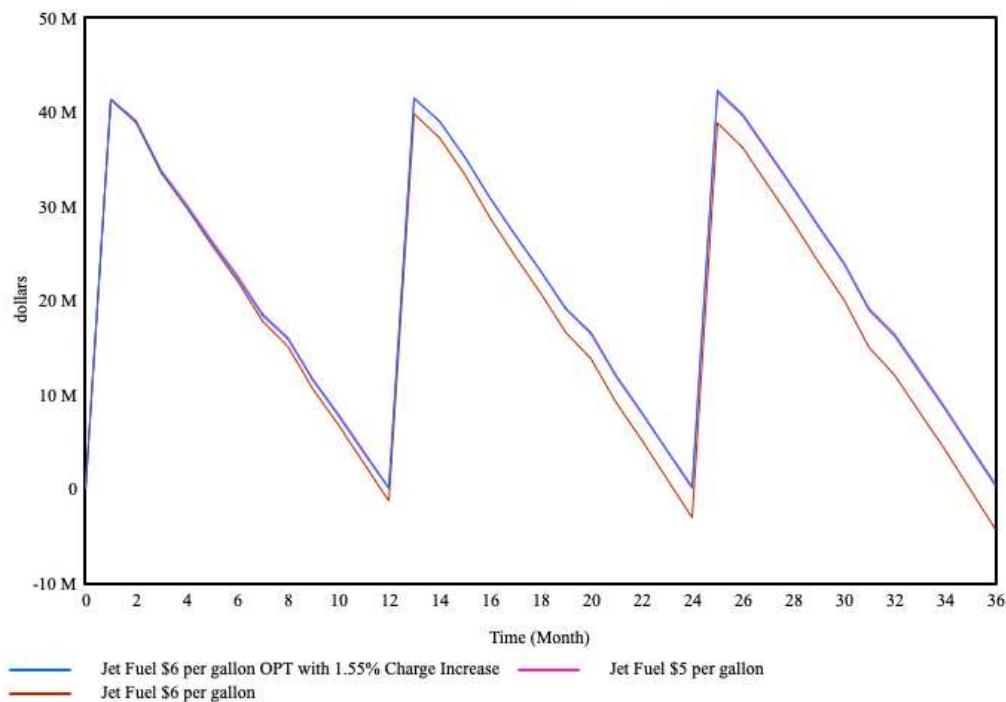


Figure 44. NASA JSC Aircraft Operations Optimized Model Graph, Increase in Charge to Customer (1.00X to 1.55X)

4) *Scenario 4: Optimization of Budget Deficit Under Increased Fuel Cost Conditions Through Reduction of Average Monthly T-38N Flight Hours*

Given the same budget deficit identified in Scenario 2 resulting from a \$1.00 USD-per-gallon increase in fuel cost, the system dynamics model demonstrates that reducing the average T-38N flight hours from 215 to 190 hours per month offsets the deficit and restores a net-zero budget balance across FY1, FY2, and FY3 (Figure 45).

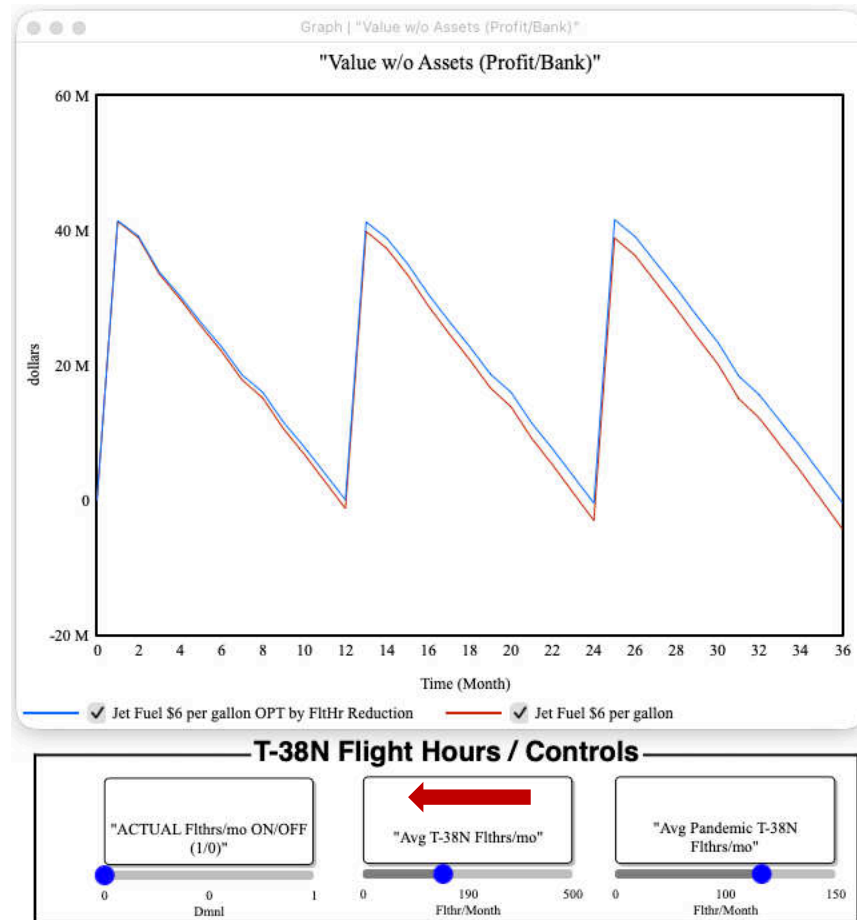


Figure 45. Reduction in T-38N Flight Hours Flown per Month to Compensate for Increased Fuel Cost.

The use of the VensimPLP® SyntheSim functionality enabled rapid evaluation of Scenarios 1, 2, and 3, with all simulations completed in a matter of seconds. These results demonstrate the flexibility, computational efficiency, and practical applicability of the system dynamics model for aircraft operations analysis, optimization, and decision support.

2.6 The NASA Enterprise System Dynamics Model (Future Capabilities)

All NASA Centers operate under similar financial requirements, executing their respective budgets through the Planning, Programming, Budgeting, and Execution (PPBE) process, as well as through reimbursable, not-for-profit external services. Likewise, most

government aircraft operations share comparable funding structures and overarching operational objectives. However, several characteristics vary among Centers, including aircraft types, mission profiles, geographic operating locations, and locality-based labor costs. Although this dissertation focuses on Center-specific aircraft operations, future development of a NASA Aircraft Operations Enterprise (NAOE) model is planned for examination in a separate study.

Personnel expenditures, including staffing levels and wage rates, constitute a substantial portion of total organizational costs. The dashboard interface (Figure 35) incorporates adjustable parameters that enable Program Managers and the Chief of the Aircraft Operations Division (AOD) to rapidly evaluate the financial implications of changes in workforce size, compensation rates, or combinations thereof during the various fiscal years. This capability may be applied at individual NASA Centers and optimized according to Center-specific budget allocations. To integrate all Centers into an Enterprise-level model, several interface standards listed below should be established:

1) Metric Standardization Across Aircraft Centers

To enable integration into an Enterprise-level system dynamics model, standardized metrics, units, and data structures must be established [32]. The operational attributes of each Center must correlate across the Enterprise, and measurement units must remain consistent to ensure valid comparisons and analyses. In other words, the model must enable direct “apples-to-apples” comparisons among Centers. Within the Enterprise model, NASA Headquarters would serve as the primary stakeholder and decision-making authority. At the Enterprise level, the model would remain relatively streamlined, focusing primarily on aggregating Center-level inputs and enabling variable modulation through the SyntheSim function.

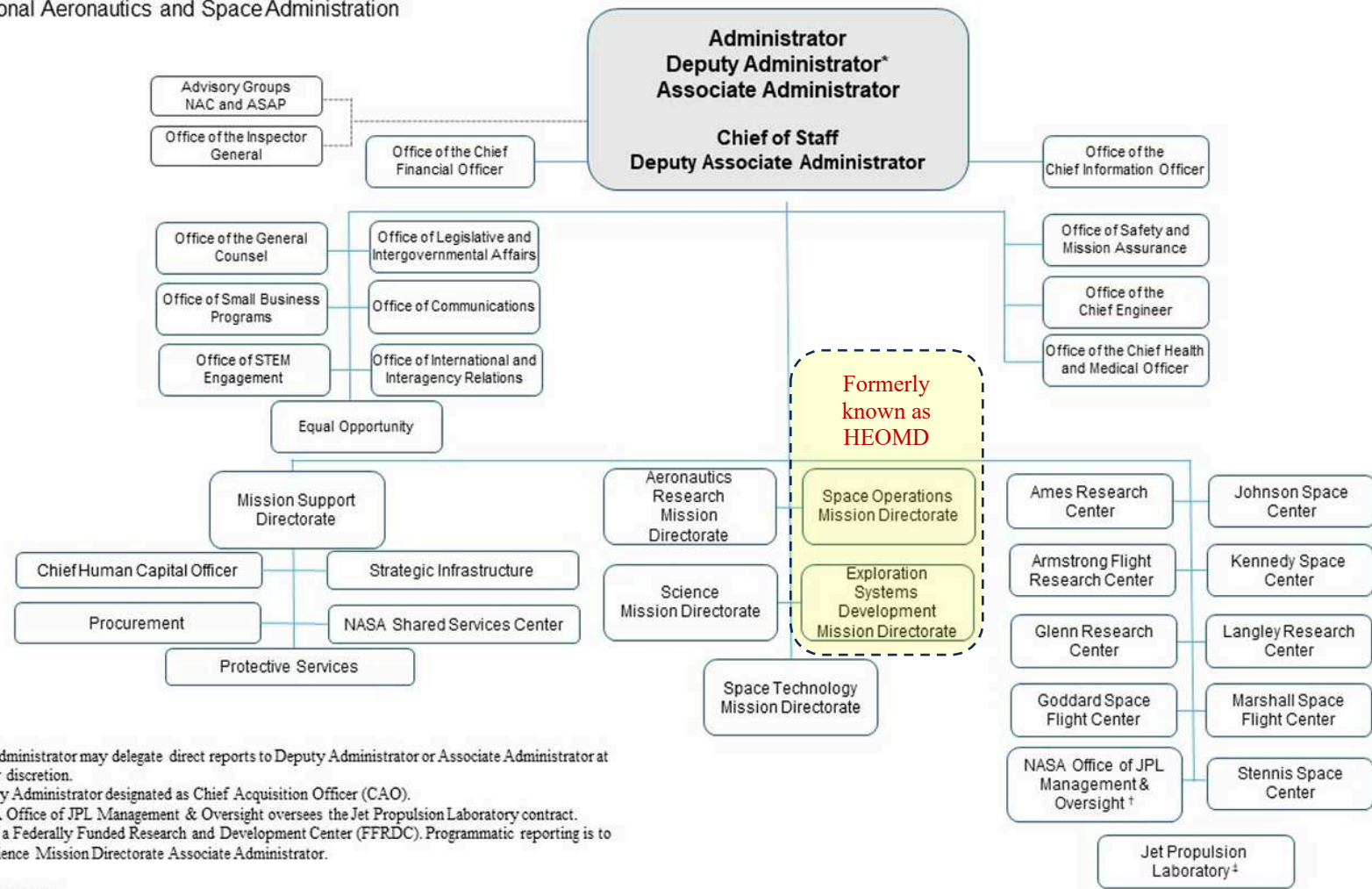
2) Use of System Dynamics Multi-Level Architecture for Each Center

The sublevels of the Enterprise system dynamics model would consist of the individual Center architectures previously discussed. While detailed model components would remain specific to each Center's operational requirements, standardized metrics and attributes would be defined to ensure compatibility and integration at the Agency level. Standardized naming conventions and measurement units would be essential to facilitate seamless and autonomous integration of multiple NASA Centers into a unified NAOE model.

3) Enterprise Stakeholder and End-State Metric Commonality

The personnel who would derive the greatest value from Enterprise-wide aircraft operations data are Agency-level decision-makers at NASA Headquarters (Figure 46). For aircraft operations in the 2019-2021 timeframe, the principal stakeholder organizations include the Aeronautics Research Mission Directorate (ARMD), the Human Exploration and Operations Mission Directorate (HEOMD), and the Science Mission Directorate (SMD). It should be noted that NASA organizational nomenclature evolved since the completion of this research. In September 2021, NASA reorganized the Human Exploration and Operations Mission Directorate (HEOMD) into two separate organizations: the Space Operations Mission Directorate (SOMD) and the Exploration Systems Development Mission Directorate (ESDMD) [33]. Subsequently, in May 2026, SOMD and ESDMD were recombined to form the Human Spaceflight Mission Directorate (HSMD). Accordingly, references to HEOMD, SOMD, and HSMD within this dissertation should be interpreted as representing the same overarching mission directorate at different points in time, reflecting NASA's organizational realignments rather than changes in the underlying mission responsibilities. Regardless, metrics between NASA Centers must be standardized to ensure merging into an Enterprise system dynamics model is seamless.

National Aeronautics and Space Administration



www.nasa.gov

Figure 46. NASA Headquarters Organization Chart [33]

At the Enterprise level, the overarching objective would be to fully execute the appropriated budget while accomplishing all mission requirements within the funded fiscal year [17] [18] [32]. Although each Center's aircraft operations system dynamics model would continue to operate according to its respective baseline architecture, the most critical Enterprise-level metric would shift from organizational "Value" to fiscal-year operational surplus or deficit. This metric would exclude fixed facility and aircraft asset values.

By enabling visibility of each Center's fiscal-year operational performance while the system dynamics model is executing through the SyntheSim function, decision-makers could dynamically increase or reduce funding allocations to specific Centers to optimize balance across the Enterprise PPBE budget [17]. Under nominal operating conditions, Enterprise stakeholders could monitor performance trends and proactively adjust resource allocations to improve operational efficiency and mission execution.

2.7 Chapter Summary

In this chapter, research was conducted to mathematically define and develop the concept of organizational Value within an aircraft operations environment. **Equation (5)** was derived and established as the foundation of the top-level system dynamics model. This equation is unique in that it provides a comprehensive framework for estimating the Value of an entity across a broad range of applications. It may be applied to for-profit organizations, nonprofit organizations, government agencies, households, or even the assessment of an individual's net worth. The equation represents a unifying framework for organizational valuation, analogous in concept to foundational equations used throughout science and engineering.

Following development of the top-level model using *Equation (5)*, subordinate model tiers were constructed based on the organizational structure of the Aircraft Operations Division (AOD) and guidance derived from NASA requirements documentation. The functionality of the system dynamics model was validated and verified through Delphi Committees and by comparison with real-world data utilized as reference modes. Upon completion of the validation and verification process, several representative operational scenarios were evaluated to demonstrate the capability and applicability of the model. These scenarios included budgetary forecasting and mitigation of increased fuel costs. The model demonstrated a high degree of capability through an integrated dashboard interface that enables efficient evaluation and expeditious determination of potential solutions.

If implemented across NASA aircraft operations centers, convergence of individual center-level models could be integrated into a comprehensive NASA Enterprise Model. Although development of this capability was beyond the scope of this dissertation, it is identified as a future integration opportunity.

CHAPTER 3: MODEL MODULARITY AND SCENARIO BASED MODELING

3.1 “9/11 Terrorist Attacks” in the United States

The September 11, 2001, terrorist attacks represent a significant historical event with profound and far-reaching impacts on individuals directly affected, including victims, their families, friends, and first responders, as well as on national and global systems. Beyond the immediate human toll, the attacks generated substantial cascading effects across the aviation sector and broader flight operations enterprise.

In the immediate aftermath, commercial aviation in the United States was suspended, resulting in an unprecedented halt to airline operations. Concurrently, military aviation operations rapidly escalated to address emerging national security threats. Over the subsequent two decades, the United States military remained engaged in sustained combat operations, driving continued demand for military air assets and personnel.

The commercial aviation industry experienced long-term volatility characterized by cyclical demand fluctuations. These fluctuations led to workforce reductions, including furloughs of pilots, flight attendants, and maintenance personnel. Many commercial airlines reported prolonged financial losses in the years following the attacks, highlighting the sector’s vulnerability to external shocks.

From a systems engineering perspective, system dynamics modeling provides a framework to analyze and anticipate the impacts of such disruptive events. By incorporating “what-if” scenarios into a system dynamics model, decision-makers can evaluate potential

system responses and implement preemptive strategies. This capability enhances organizational resilience by enabling proactive planning for low-probability, high-impact events.

3.2 Russia Invasion of Ukraine

The Russian invasion of Ukraine in early 2022 contributed to a rapid acceleration in global inflation, particularly within the energy sector. On March 8, 2022, U.S. President Joe Biden announced a ban on the import of Russian oil. Several allied nations implemented similar restrictions, significantly constraining global oil supply. This disruption induced substantial volatility in supply–demand dynamics, resulting in a sharp increase in crude oil prices.

As a direct consequence, aviation fuel prices experienced a significant surge. The cost of aviation fuel increased from approximately \$2.36 USD-per-gallon in January 2022 to \$6.90 USD-per-gallon by May 2022. Figure 47 illustrates the cascading effects of the Russian oil embargo on aviation fuel pricing.

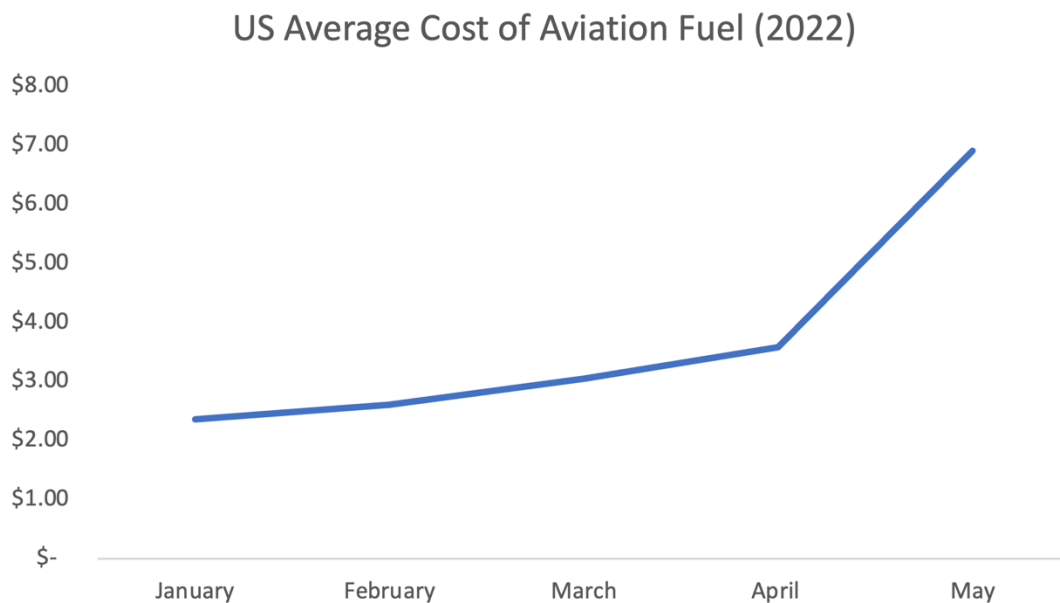


Figure 47. US Average Cost of Aviation Fuel Jan-May 2022 (\$USD-per-gallon)

This scenario, initially introduced in Section 2.5.2, was previously modeled in Scenario 2 (Figure 41 and Figure 42) and further optimized in Scenario 3 (Figure 43 and Figure 44) and Scenario 4 (Figure 45). In addition, the International Air Transport Association (IATA; [88]) provides longitudinal tracking of jet fuel prices, reported in U.S. dollars (USD) per barrel (bbl). Figure 48 illustrates jet fuel price trends from January 2016 through March 2026. Three major geopolitical and socioeconomic events that significantly influenced jet fuel prices are identified in the figure. The first is the onset of the COVID-19 pandemic in March 2020. The second is the disruption to global energy markets following the Russian invasion of Ukraine and the subsequent international sanctions imposed on Russia beginning in February 2022. The third is the escalation of the U.S.–Israel conflict involving Iran in early 2026. Collectively, these events demonstrate the sensitivity of jet fuel prices to major geopolitical and socioeconomic disruptions, highlighting the importance of incorporating fuel-price volatility into long-term operational and financial planning models.

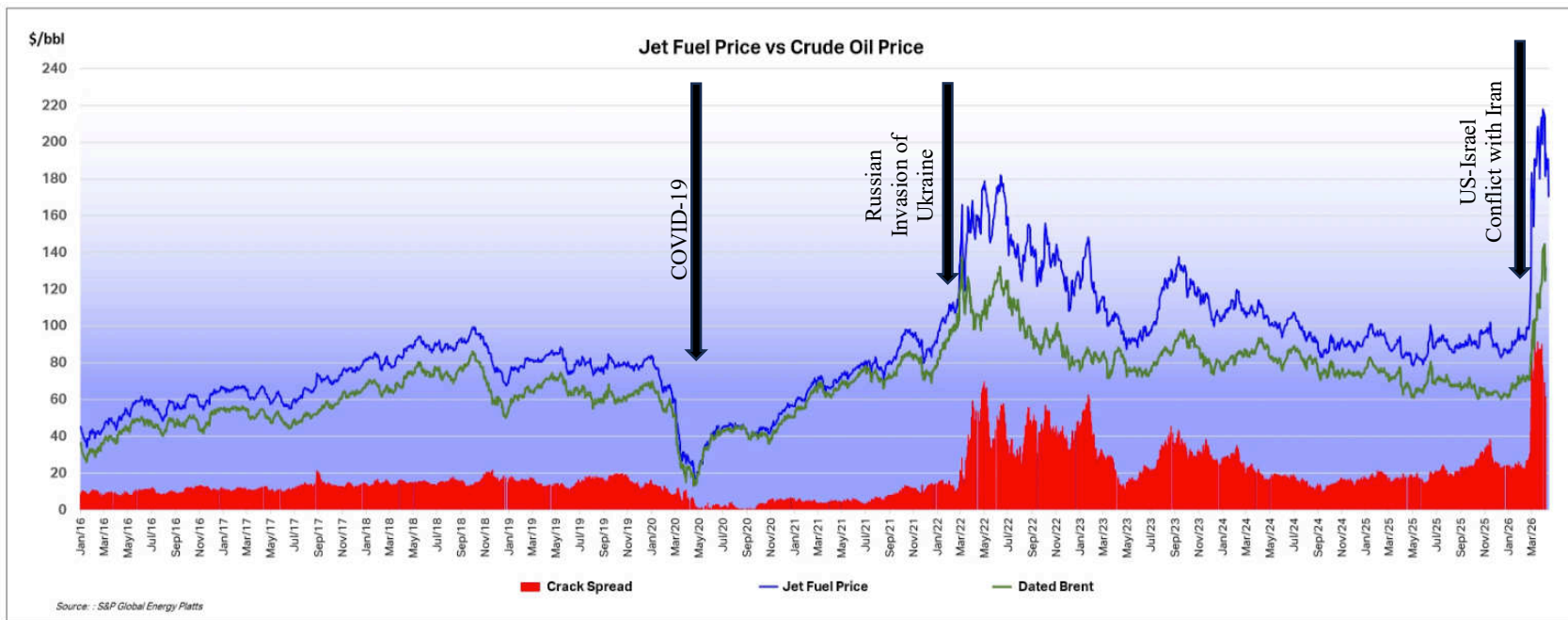


Figure 48. Jet Fuel Price (Blue) vs. Crude Oil Price (Green) over a span of the past 10 years [88]

3.3 COVID-19 Pandemic Regulations and Fear of Infection

As the commercial airline industry was recovering from the long-term impacts of the September 11 attacks and returning to profitability, the emergence of the COVID-19 Pandemic in 2020 introduced a new and significant disruption. While the effects were not as instantaneous as those following 9/11, they can be reasonably modeled as immediate within the context of the baseline system dynamics framework. The model operates on a 1/4-month time step, and the interval between the first reported case in the United States and the implementation of federal shutdown mandates was approximately 1 to 1.5 months.

The commercial aviation sector experienced substantial operational and financial impacts due to both government-imposed restrictions and public concern regarding exposure to infection in confined aircraft environments with recirculated air. Consequently, passenger demand declined sharply, leading to significant revenue losses across the industry. Similarly, within National Aeronautics and Space Administration (NASA), total flight hours were reduced, and mission priorities were adjusted to align with evolving safety requirements.

At the Aircraft Operations Division (AOD), flight operations were deliberately scaled back to minimize personnel exposure, both within the facility and during Aircraft on Ground (AOG) scenarios at remote locations. Figure 49 illustrates key events influencing flight-hour reductions at AOD. Operations of the T-38N aircraft were limited primarily to maintaining Instructor Pilot (IP) currency, while astronaut flight activity was reduced to essential minimums, often conducted alongside IPs to further mitigate exposure risk.

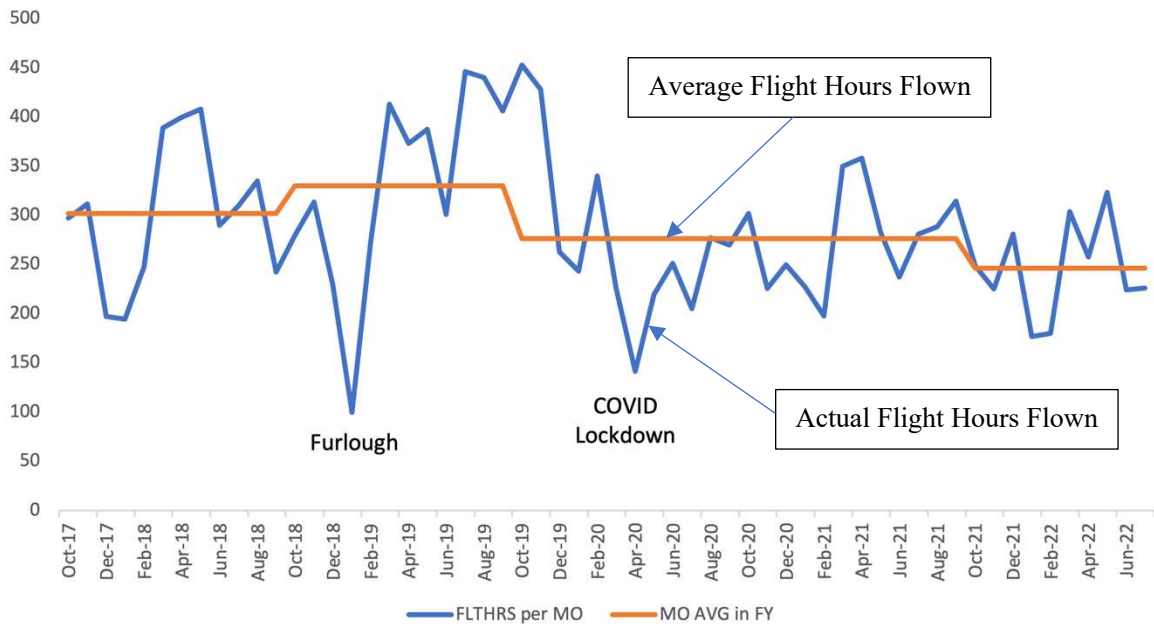


Figure 49. Actual AOD Flight Hours Flown Summary FY18-FY22

In-person meetings within AOD and across NASA were transitioned entirely to remote formats. Airborne science missions were either postponed or canceled, reflecting broader operational constraints. Concurrently, Gulfstream aircraft were repurposed to transport astronauts and other mission-essential personnel to training events, launch sites, and recovery operations, thereby reducing reliance on commercial air travel and limiting exposure risk.

Leadership implemented comprehensive COVID-19 protocols to safeguard both passengers and aircrew. These measures were integral to maintaining mission continuity while prioritizing health and safety during the pandemic.

3.4 Updated Model to Incorporate Pandemic Effects

Socioeconomic disruptions can have significant, and often adverse, impacts on aircraft operations organizations. To account for these effects, the baseline system dynamics model developed in Chapter 2 was enhanced to incorporate pandemic-related conditions. Specifically,

three additional parameters were introduced: a pandemic trigger, pandemic duration (in months), and the pandemic start month (Figure 50).

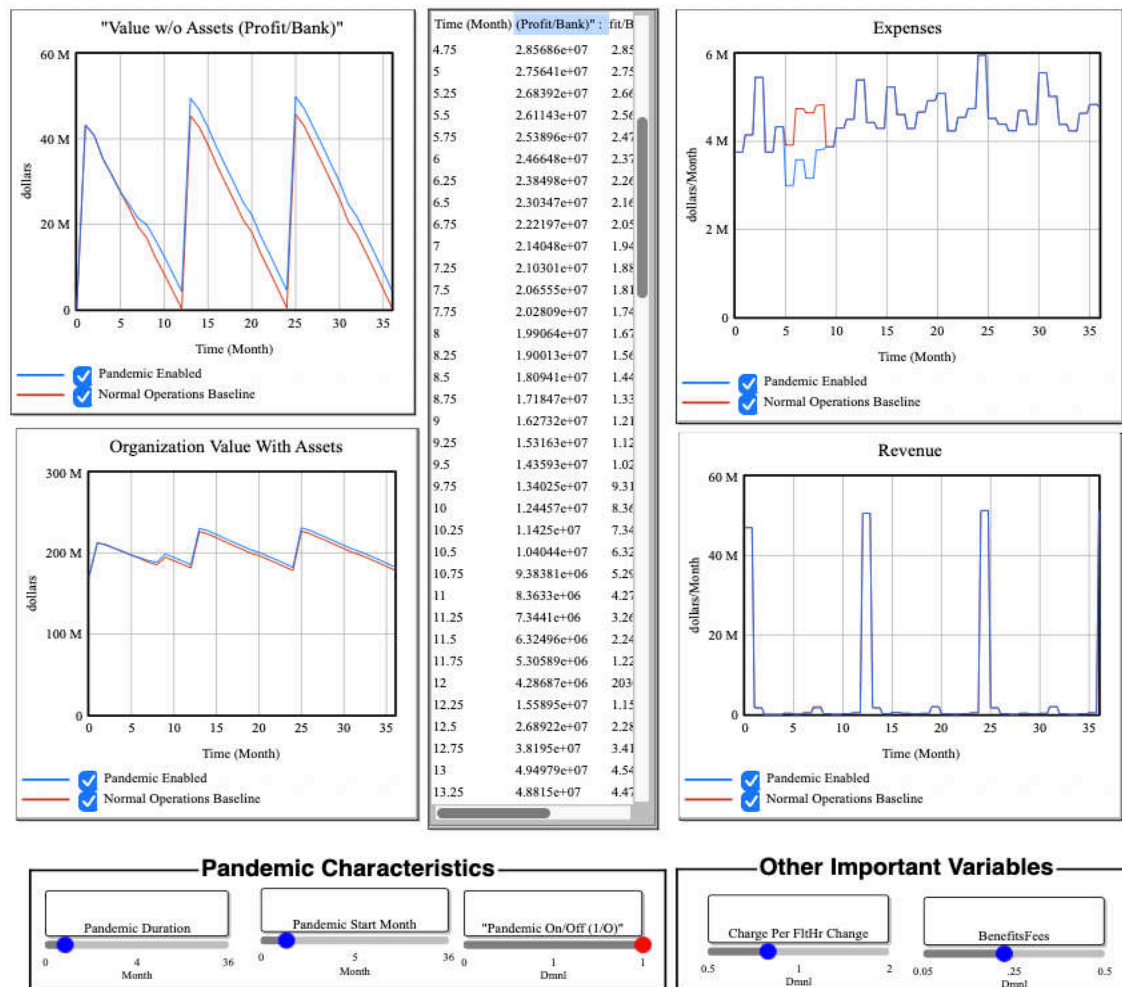


Figure 50. System Dynamics Model Dashboard Showing Pandemic Functions

When the pandemic trigger is set to “0,” the system dynamics model operates under nominal conditions, as described in Chapter 2. When the trigger is activated (“1”) and the associated parameters are defined, the model simulates the operational and financial impacts of a pandemic over the specified time horizon.

Model verification and validation were performed using historical operational data, including recorded flight hours and revenue inflows observed during pandemic conditions. These

data were obtained through a combination of archival research and structured interviews with Program Managers representing each aircraft platform. Additionally, the Aircraft Operations Division (AOD) Business Manager was consulted to ensure the accuracy of financial data and to provide organizational concurrence regarding model assumptions and outputs.

Following initial model execution under both pandemic and non-pandemic scenarios, a second Delphi Committee review was conducted. The committee evaluated the model structure, underlying assumptions, and resulting outputs and concluded that the model was satisfactorily validated and verified as being useful and sufficiently accurate.

3.4.1 Effects of the System Dynamics Model with an Active Pandemic Event

The baseline System Dynamics model incorporates a logical “trigger” mechanism that employs conditional (“if-then”) statements to activate pandemic-specific parameters during a defined disruption period. In the scenario illustrated in Figure 51, the onset of the pandemic occurs four months after model initiation and persists for a duration of five months. At the beginning of the ninth month, the model automatically reverts to nominal flight operations.

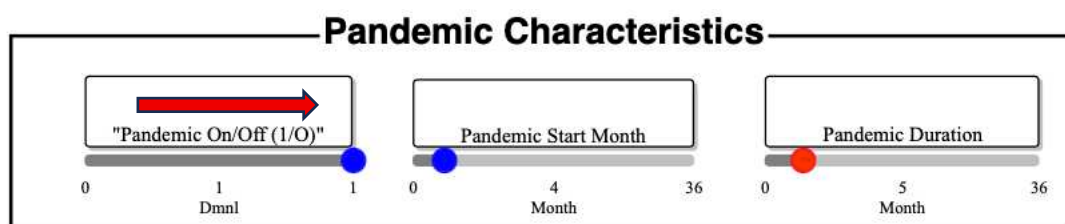


Figure 51. SyntheSim Slidebars for Initiating a Pandemic Event

Figure 52 illustrates the aggregate impact of the pandemic, which begins after Planning, Programming, Budgeting, and Execution (PPBE) funding for the first fiscal year has already been allocated. Due to the substantial reduction in flight hours during the pandemic period, the organization experiences a temporary financial surplus (i.e., excess funds) at the conclusion of

the first fiscal year. However, this apparent financial benefit is achieved at the expense of a significant degradation in aircrew proficiency and the suspension of airborne science missions.

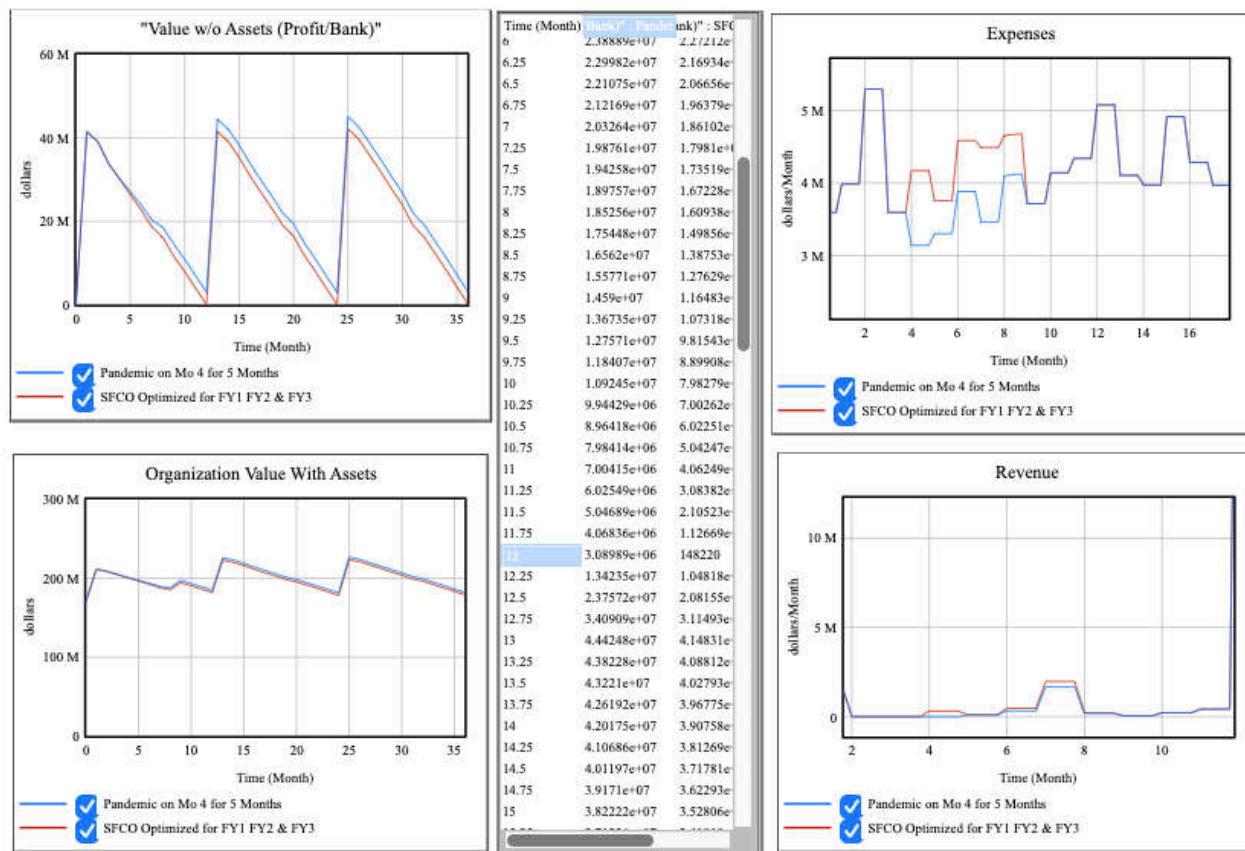


Figure 52. NASA JSC Aircraft Operations Model Graph with Pandemic Model Enabled, Pandemic Start Month of 4, and Pandemic Duration of 5 Months

A key capability of SyntheSim utilized in this analysis is the ability to overlay multiple scenarios, thereby enabling rapid, near-real-time comparison of variations in critical performance metrics. In this scenario, the sharp decline in flight hours during fiscal year 2020 (FY2020) (see Figure 22) results in a corresponding reduction in variable operational costs, as shown in Figure 53. Although essential missions continue to be executed, financial reserves accumulate because funding allocations were based on a nominal operational tempo.

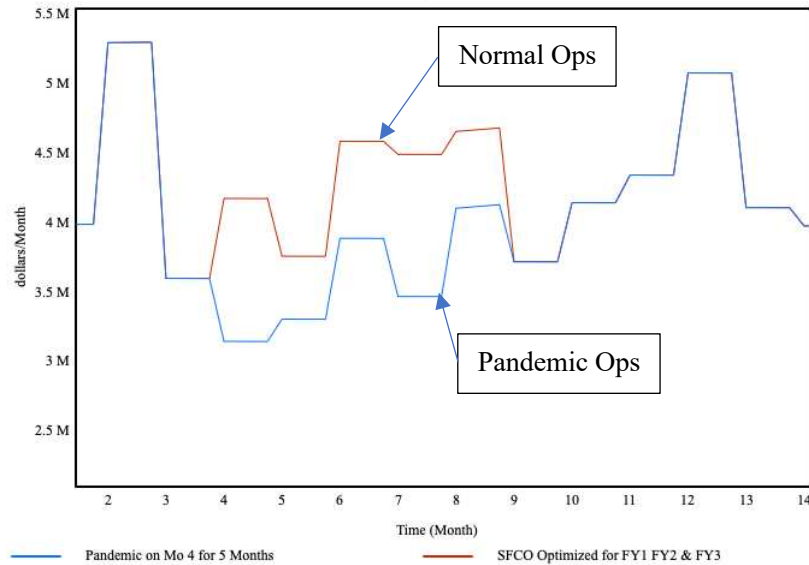


Figure 53. System Dynamics Model Output of Expenses Illustrating Changes in Operational Expenses During a Pandemic

Absent corrective action, these excess funds would be subject to reallocation, either through return to Headquarters at the conclusion of the fiscal year or redistribution to other NASA Centers experiencing budget shortfalls. It is important to note that this phenomenon was not isolated to AOD during the fiscal year of the pandemic; similar funding under-execution trends were observed across multiple NASA Centers where allocated budgets were not fully expended by the end of the fiscal year.

3.4.2 Optimizing the Effects of a Pandemic Event Through Reallocation of Excess Funds

The effects of a pandemic scenario can be readily evaluated using the SyntheSim function; however, simulation results indicate the generation of significant excess funds. As illustrated in Figure 52, absent corrective action, projected profits substantially exceed the fiscal year (FY) “net-zero” target by approximately \$3.09M USD by the end of FY1. Consequently, the organization must implement mitigation strategies to manage excess funding, including reducing revenue-generating activities, increasing expenditures (e.g., spare parts procurement),

or redistributing funds to other Centers experiencing budget shortfalls. The system dynamics model developed in this dissertation possesses the capability to evaluate and accommodate these mitigation strategies.

3.4.3 *Optimizing the Effects of a Pandemic Event Through Spare Parts Procurement*

During the COVID-19 pandemic, the organization utilized approximately \$3.09M USD in excess funds to enhance operational capability through the procurement of spare parts and the implementation of additional safety initiatives. Using the system dynamics model dashboard, a bulk spare parts procurement strategy can be initiated before the end of the current fiscal year (FY1) to reallocate excess funds resulting from reduced flight operations during the pandemic, beginning in Month 10 of FY1. The dashboard interface includes a sidebar (Figure 54) that enables balancing of end-of-year funding levels by adjusting procurement expenditures (Figure 55 and Figure 56). Bulk spare parts procurement was the actual mitigation strategy implemented by the Aircraft Operations Division (AOD) during FY2020 to utilize excess funds generated during the pandemic period.

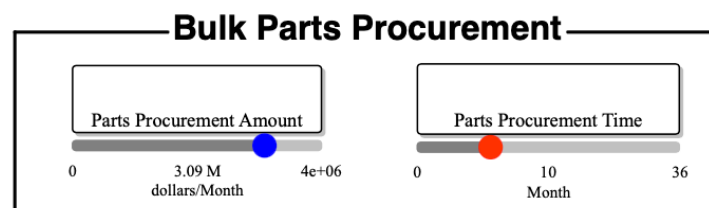


Figure 54. System Dynamics Model Dashboard Bulk Spare Parts Procurement Sidebar

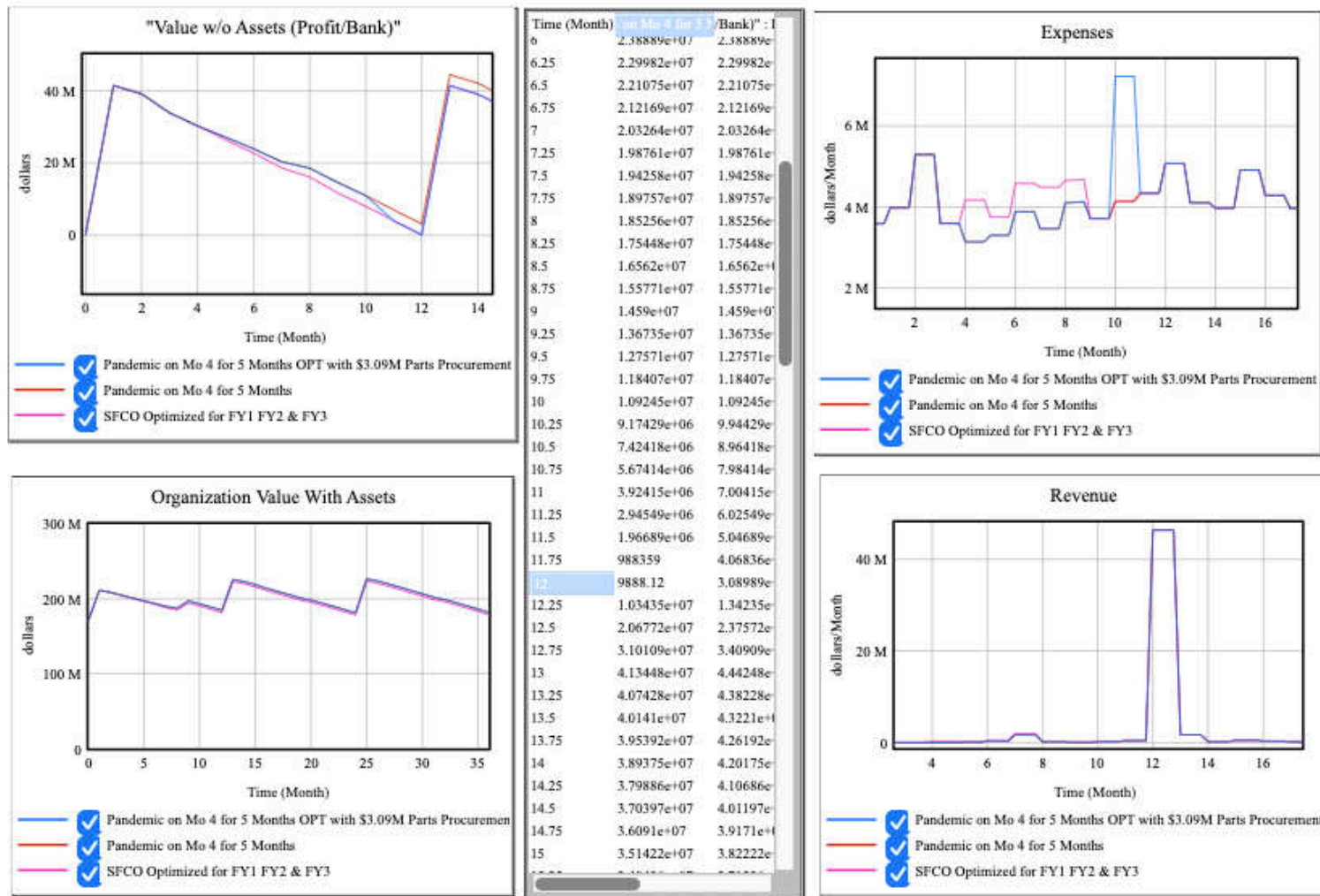


Figure 55. System Dynamics Model Dashboard Optimizing Pandemic Effects Through Bulk Spare Parts Procurement of \$3.09M USD in Month 10

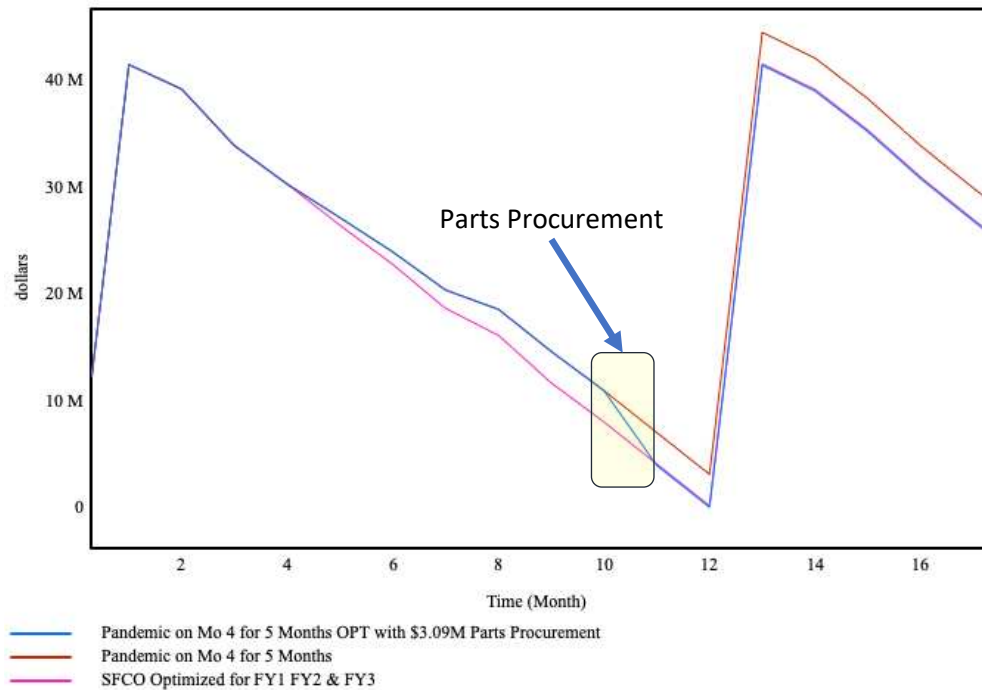


Figure 56. System Dynamics Model Illustrating Organizational “Value” When Optimizing Pandemic Effects Through Spare Parts Procurement of \$3.09M USD

3.4.4 Optimizing the Simultaneous Effects of a Pandemic Event, Increased Fuel Costs, and Budget Reductions Through Multiple Managerial Strategies

One of the primary capabilities of the system dynamics model is its ability to balance multiple operational variables to address individual or combined real-world events and scenarios. For example, using the nominal operational budgeting strategy established in Section 2.5.2, consider a scenario in which a pandemic occurs during Month 14 and persists for five months, jet fuel prices increase from \$5 to \$6 USD-per-gallon beginning in FY2, and the SFCO budget is reduced by \$5M USD in FY3. The following assumptions and conditions apply:

Given:

- Original balanced SFCO funding levels for FY1, FY2, and FY3 of \$45.0M, \$45.8M, and \$47.4M USD, respectively
- Standard non-pandemic operational conditions
- Figure 40 illustrates the balanced nominal model

Scenario:

- A pandemic is initiated in Month 14 and continues for a duration of five months
- Jet fuel prices increase by \$1 USD-per-gallon beginning in FY2 and remain elevated through FY3 (FY1 = \$5 USD, FY2 = \$6 USD, FY3 = \$6 USD)
- The FY3 SFCO budget is reduced by \$5M USD, from \$47.4M USD to \$42.4M USD
- Figure 57 illustrates the dashboard configuration used to initiate the scenario
- End-of-year results without optimization are as follows: FY1: \$0 USD, FY2: +\$1.72M USD, and FY3: -\$4.52M USD

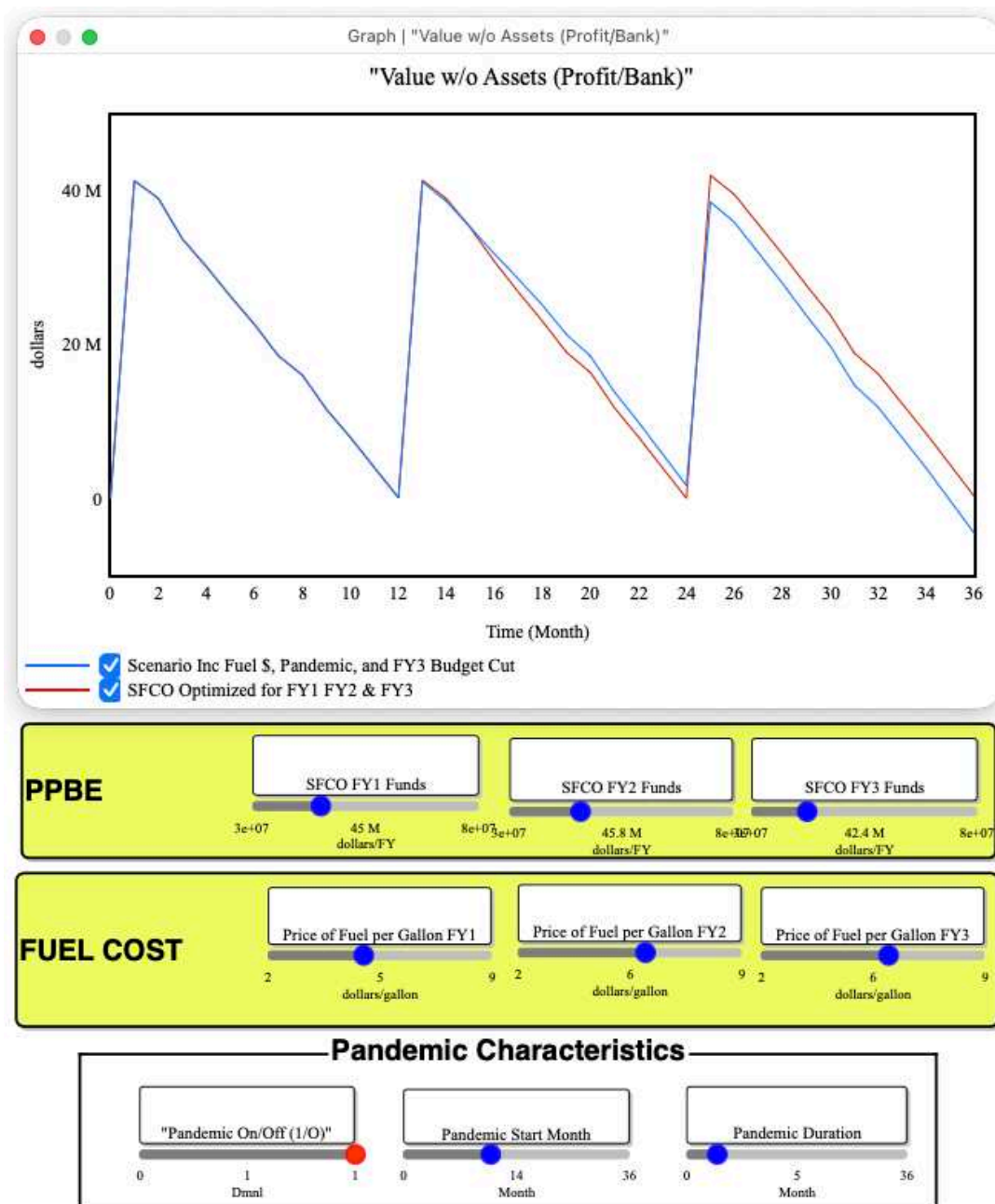


Figure 57. Dashboard Configuration for Initiating Multiple Scenario Conditions

Optimization Strategy:

- **Primary objective:** Achieve net-zero *Value without Assets* at the conclusion of FY1, FY2, and FY3
- Increase safety initiative funding in FY1 from \$25K USD-per-month to \$57K USD-per-month
- Increase non-T-38 customer charges as follows:
 - FY1: Increase to 1.1% to support expanded safety initiatives
 - FY2: Increase to 1.3% to offset the increase in jet fuel costs to \$6 USD-per-gallon
 - FY3: Increase to 1.6% to accommodate sustained fuel cost increases and budget reductions
- Execute a parts procurement expenditure of \$2.44M USD in Month 22 to utilize excess funds resulting from reduced pandemic-related operations
- Transfer FY2 parts procurement credits into FY3 to mitigate the effects of the budget reduction (\$20,333 USD-per-month of bulk parts credit transferred from FY2 to FY3)
- Reduce average T-38N flight hours in FY3 from 215 to 190 hours-per-month to support budget stabilization
- Reduce staffing levels by one Government Service (GS) employee and eight contractor support (CS) personnel
- Figure 58 illustrates the optimized *Value without Assets* results, while Figure 59 illustrates the associated dashboard configuration

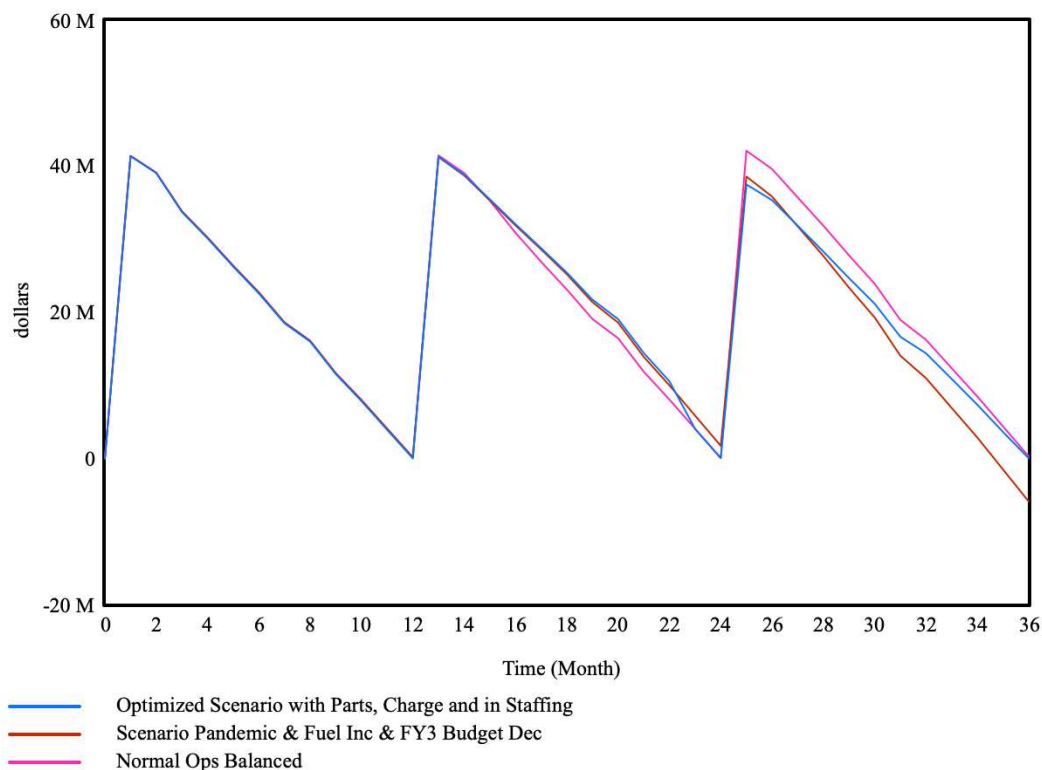


Figure 58. System Dynamics Output of “Value w/o Assets” for Optimized Results

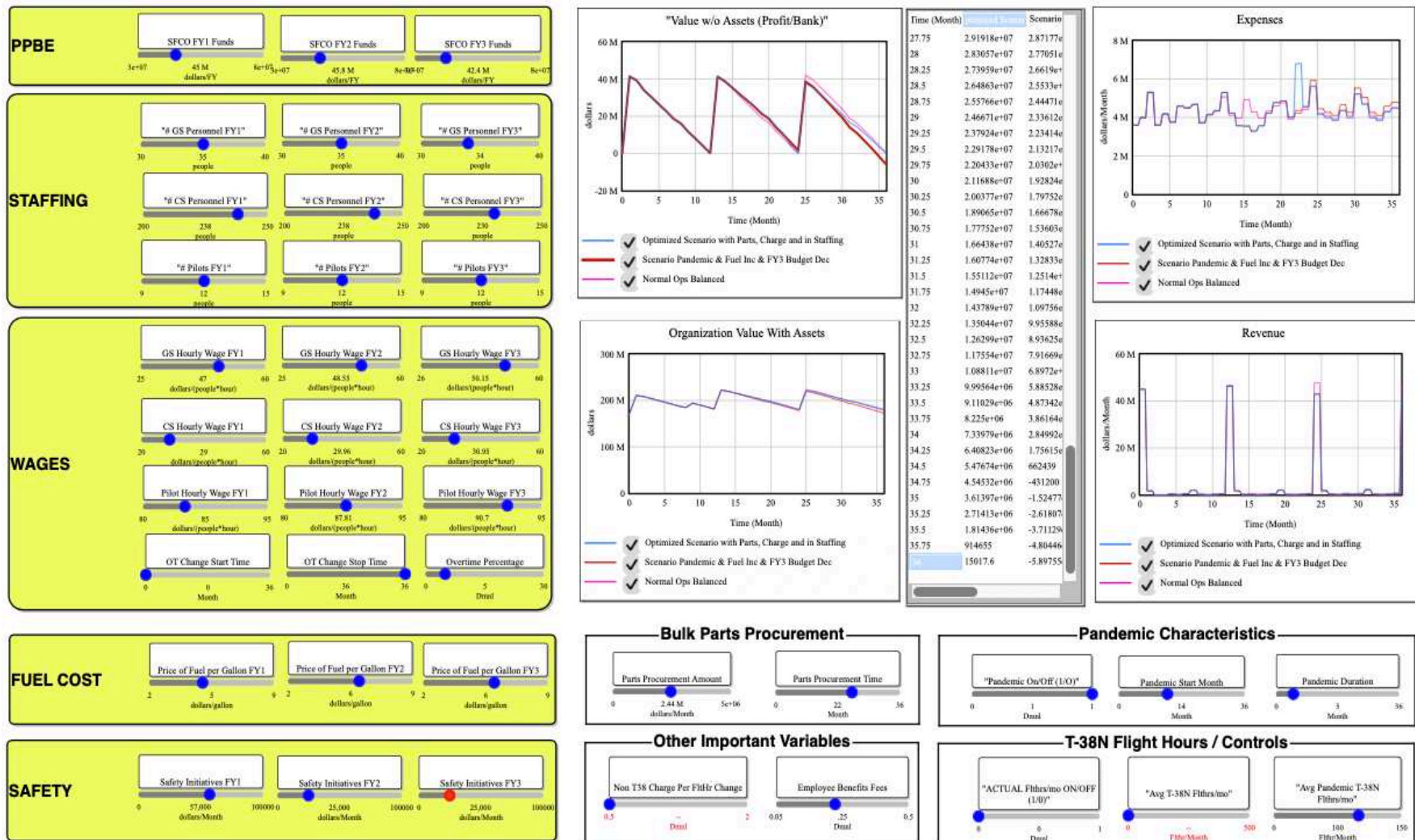


Figure 59. System Dynamics Dashboard Configuration for Optimized Multiple Scenario Conditions

The above example demonstrates the versatility of the system dynamics model in balancing fiscal year budgets under severe operational constraints through the strategic application of available resources. Although workforce reductions should be considered a measure of last resort, the model indicates that the reduction of one civil servant and eight contractor support personnel is necessary in FY3 to achieve budget equilibrium after other mitigation strategies have been implemented. However, workforce reductions may also introduce morale and safety concerns. The model further demonstrates that a \$5M USD reduction in the FY3 budget, combined with increased fuel costs, can produce significant operational consequences. These consequences may include the loss of institutional experience, increased employee workload resulting from reduced staffing, and decreased flight-hour proficiency, all of which may adversely affect operational safety and effectiveness.

A real-world example of this vulnerability occurred in January 2025, when AOD experienced a mid-fiscal-year multi-million-dollar reduction in its FY25 budget, resulting in the termination of just over 0.4% of its contractor personnel. Consequently, the scenario modeled herein represents a realistic and operationally plausible undesirable outcome.

3.5 Investing in Safety Mitigation Strategies Using the System Dynamics Model

Safety is a foundational component of any aviation organization [89, p. 45]. The system dynamics model layer for Fixed Costs is presented in Figure 30 and can be efficiently managed through the dashboard and SyntheSim functionality, as illustrated in (Figure 60).

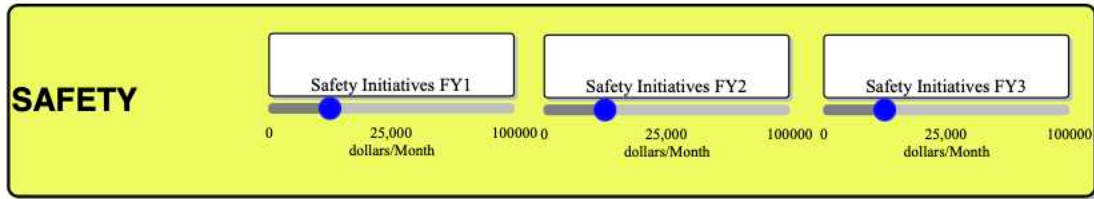


Figure 60. System Dynamics Model Safety Initiatives Slidebar (Dashboard)

Proactive investment in safety initiatives may be considered to produce “ghost” benefits, as the effectiveness of mishap prevention is inherently difficult to quantify. Specifically, organizations cannot directly measure the number of mishaps that were prevented because these events never materialize. Instead, aviation organizations primarily assess safety performance using metrics such as mishap occurrence rates per 100,000 flight hours or comparable indicators. Consequently, the true extent of mishap prevention remains an inherently unknown variable.

At the Johnson Space Center (JSC), an Aviation Safety Office has been established and includes specialists responsible for managing the organization’s Safety Management System (SMS), mishap investigations, and associated safety programs. The currently funded staffing level consists of 4.6 Full-Time Equivalents (FTEs). These personnel costs are embedded within the Flight Operations Directorate budget and are not incorporated into the Aircraft Operations Division (AOD) staffing plan.

A need exists for an additional full-time Human Factors Safety Specialist and a part-time System Dynamics Specialist, positions that are not currently funded. This additional 1.5 FTE requirement is estimated at approximately \$300,000 USD annually, based on an average cost of \$200,000 USD-per-FTE, which includes an annual salary of approximately \$153,846 USD plus an additional 30% for benefits [90]. It is acknowledged that a single individual with expertise in

both disciplines could potentially fulfill these responsibilities; however, for the purposes of this dissertation, a staffing requirement of 1.5 FTEs is assumed.

In addition to existing job responsibilities, personnel are assigned collateral duties associated with participation in mitigation efforts, including safety committees and related initiatives. To ensure continued proficiency in safety-related functions, additional professional training should also be considered. Furthermore, operation of the system dynamics model requires software subscriptions, including the commercial version of VensimDSS®. A breakdown of the annual expenditures incorporated into the baseline model is provided in Table 3. For the purposes of the system dynamics model, monthly expenditures for safety initiatives are estimated at \$25,000 USD.

Table 3. Safety Initiatives Cost Breakdown (in \$ USD)

Resource	Cost/Year	Cost/Month
0.5 FTE (SD Modeler)	\$100,000 [90]	\$8,333.33
1.0 FTE (Human Factors)	\$200,000 [90]	\$16,666.67
VensimDDS® Subscription	\$2200 [91]	\$183.33
Committee Participation (4 people, 1 hours per week)	\$16,640	\$1,386.67
Training Courses (1 additional course per year)	\$3,000 [92]	\$250
Total Cost	\$321,840	\$26,820

3.6 Chapter Summary

This chapter utilized the baseline aircraft operations model developed in Chapter 2 to simulate and optimize a variety of extreme operational scenarios, demonstrating the model's

utility and versatility. The scenarios examined included real-world events previously experienced by flight organizations, such as increases in jet fuel prices, pandemic-related disruptions that significantly reduced flight operations, and budget reductions. Through interviews and documented operational data, safety initiatives were also modeled to evaluate the extent to which mitigation strategies should be implemented and to determine their relative effectiveness. In the most extreme scenario analyzed (Section 3.4.4), workforce reductions were determined to be necessary. The resulting system dynamics model serves as a proactive decision-support tool that may be used to justify and defend budgetary requirements when higher-level financial managers propose reductions to previously programmed funding.

In addition to operational optimization, this chapter examined safety mitigation strategies in greater detail. This analysis provided insight into the value of incorporating additional safety resources within the organization and demonstrated the potential for substantial benefits to organizational performance, operational effectiveness, and long-term mission success.

CHAPTER 4: BRIDGING RESOURCE EFFICIENCY TO SAFETY STRATEGIES

Optimizing an organization through financial metrics, as previously discussed, yields compounding benefits across operational domains. System dynamics simulations not only enable organizations to project program funding across current and future fiscal years but also support the strategic allocation of additional resources toward training, safety mitigation initiatives, and the procurement of mission-critical equipment. These capabilities enhance both operational effectiveness and risk management. By forecasting and programmatically distributing funds throughout the fiscal year, organizations can establish financial reserves that facilitate proactive scheduling of personnel training. Furthermore, optimizing aircrew flight hours enables targeted development of specialized experience while improving overall proficiency for both aircrew and maintenance personnel.

Jim Wetherbee, a Hall of Fame astronaut and author, emphasized the limitations of traditional investigative approaches, stating, “Investigation conclusions are linear and causal. After understanding what happened through event-based analysis, the organization should conduct a systems-based analysis using systems thinking to determine why those events occurred.” He further noted that “a systems-based analysis yields better learning,” as it allows investigators to understand why decisions and actions appeared appropriate to managers and operators operating within a complex sociotechnical system. This approach enables the development of corrective actions that address systemic influences, thereby reducing the likelihood of recurrence. Corrective actions derived from systems-based analyses are therefore more effective in preventing future accidents [93, p. 5].

Wetherbee's perspective is informed by firsthand experience within the astronaut corps during the Space Shuttle Challenger and Space Shuttle Columbia mishaps, where human factors played a significant role in catastrophic outcomes. Similarly, Diane Vaughan highlighted the organizational dimensions of failure in her analysis of the Space Shuttle Challenger accident, noting that improved organizational management can reduce the likelihood of errors leading to mishaps. She further emphasized that "the effect of unacknowledged and invisible social forces on information, interpretation, knowledge, and, ultimately, action is very difficult to identify and control" [94]. These findings provide strong evidence that human factors are primary contributors to major aerospace disasters.

This chapter describes the current NASAHFACS process, NASA's specialized Human Factors Analysis and Classification System and introduces enhancements that enable each identified factor to be assigned a quantified "impact" value. This quantitative approach allows for the comparison of severity across multiple anomalies and disciplines. Incorporating human factor impact data into the analytical framework provides a more robust basis for prioritizing risk and optimizing resource allocation, thereby strengthening both safety outcomes and organizational performance.

4.1 Human Factors Analysis and Classification Defined

Negative human factors, herein referred to as "Red Lights," are primary contributors to aviation anomalies and mishaps. Conversely, positive human factors, or "Green Lights," are those conditions or actions that mitigate risk, prevent escalation, or interrupt the progression of an event toward a more severe outcome [95].

The systematic identification, categorization, and analysis of these factors through the Human Factors Analysis and Classification System (HFACS) enables organizations to make informed decisions regarding resource allocation. Specifically, HFACS supports both the mitigation of recurrent adverse events and the reinforcement of effective, safety-enhancing behaviors.

Effective HFACS application requires specialized training to ensure a comprehensive understanding of causal mechanisms and contributing conditions during investigations [66] [95] [96]. This process necessitates qualified personnel who are empowered to provide candid assessments, voice professional judgments, and offer actionable recommendations throughout the classification and analysis process.

4.2 Human Factors Analysis and Classification System (HFACS) Introduction

Human Factors, and more specifically Aviation Human Factors Analysis and Classification, constitute a critical field of study focused on understanding the interactions between human operators and the complex systems in which they function [97]. This domain encompasses cognitive, physical, and organizational dimensions that influence human performance and contribute to operational errors or inefficiencies within aviation environments [53] [98]. A thorough understanding of these dimensions is essential for improving safety, operational efficiency, and system reliability. Aviation human factors research examines how pilots, air traffic controllers, maintenance personnel, and other aviation professionals interact with both their operational environment and each other [99].

As noted by Xiong et al., “Human factors may interact with machine, environment, and organizational factors, which exert a coupled impact on flight safety. Therefore, exploring the

coupling mechanisms between human and other factors is of significant value, as it supports the development of targeted operational training and safety management strategies” [100, p. 2].

The aviation safety field acknowledges that human error is a dominant contributor to aviation incidents and accidents, accounting for approximately 70–80% of all mishaps [53] [89]. Consequently, the systematic analysis and classification of human factors are essential for identifying root causes, informing corrective actions, and ultimately preventing recurrence while enhancing overall aviation safety [93].

4.2.1 Error Subcategories

The Human Factors Analysis and Classification System (HFACS) framework was developed by Drs. Wiegmann and Shappell (Figure 61) [89] and is conceptually aligned with Dr. James Reason’s “Swiss Cheese” model (Figure 62) [101]. This framework provides a structured methodology for identifying and categorizing human error within complex systems.

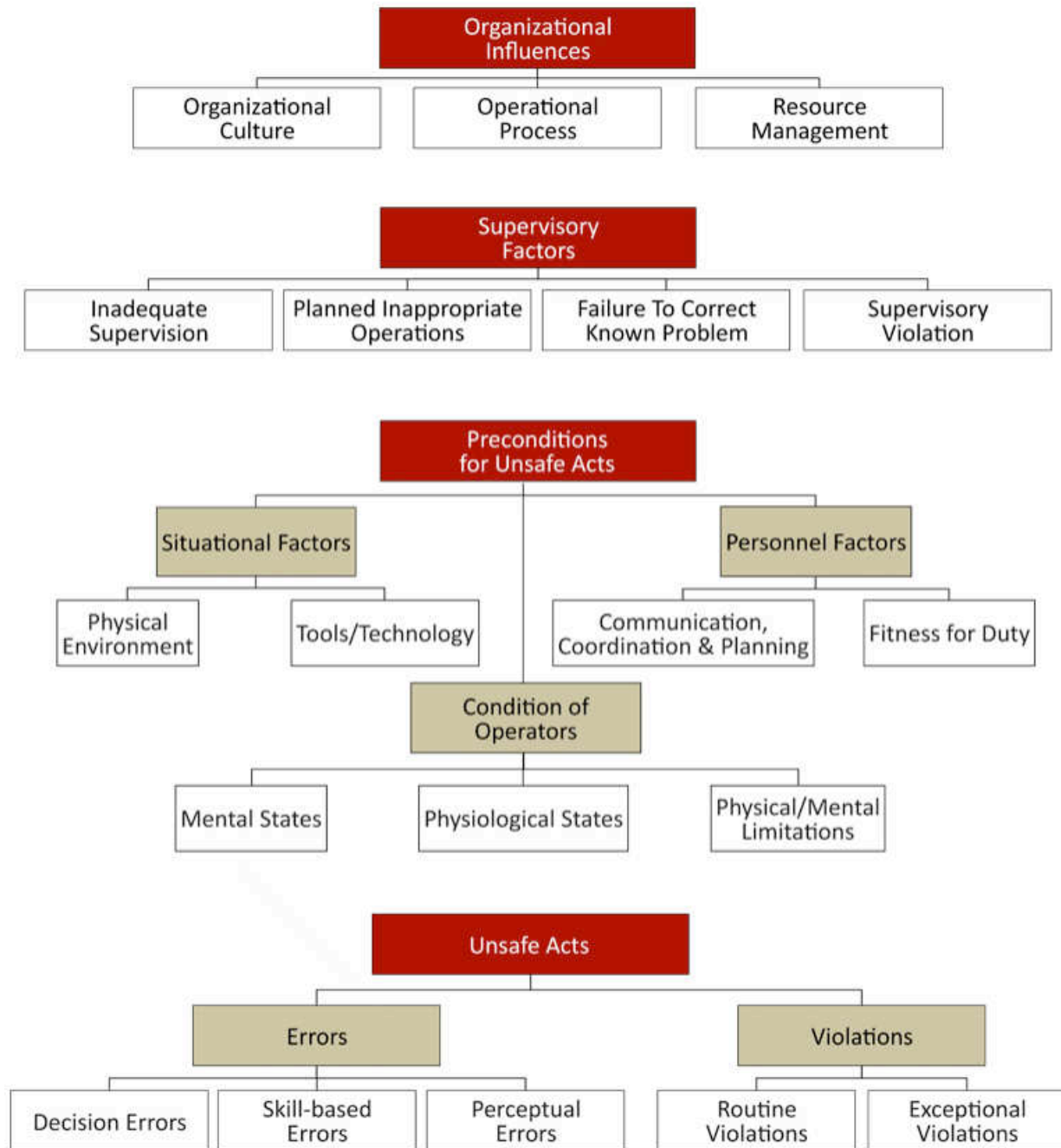


Figure 61. Weigmann and Shappell's HFACS Framework Model [89]

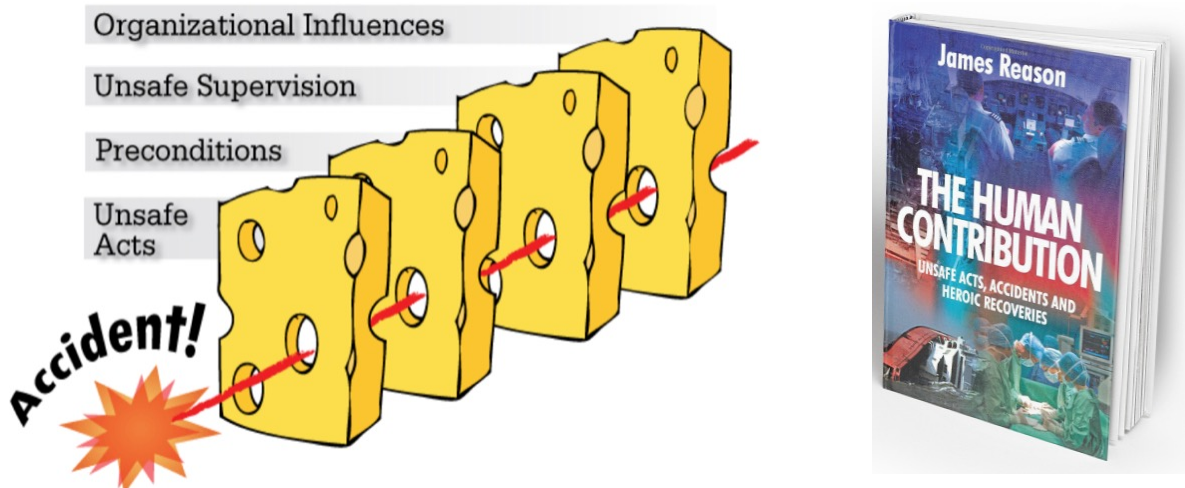


Figure 62. James Reason's Swiss Cheese Model [101]

Building upon Reason's theoretical foundation, Wiegmann and Shappell adapted the model specifically for aviation operations and system-level analysis. As aircraft technologies continue to advance and safety margins improve, the relative contribution of human error has increased. This shift is largely attributed to the growing complexity of integrated systems and increased operational demands, including higher traffic density and mission variability [89] [102]. Figure 63 illustrates longitudinal trends in human and technical causation over a 121-year period, highlighting this evolving relationship [89] [103].

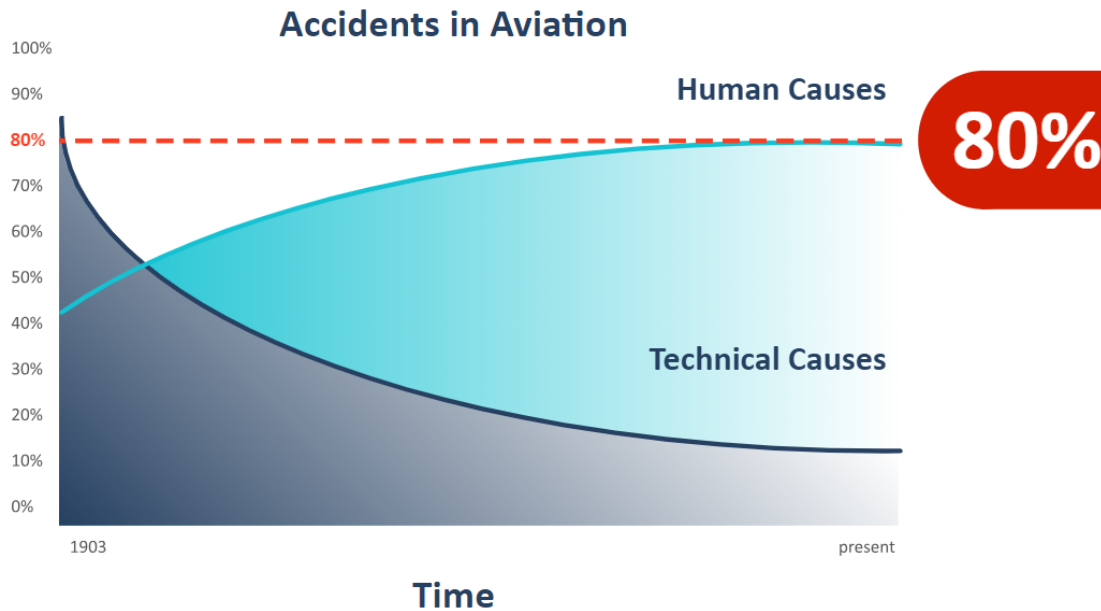


Figure 63. Trend of Accident Causations 1903-Present [89]

HFACS is a structured and systematic process, requiring that investigators, managers, operators, and maintenance personnel are adequately trained in its application and interpretation [60] [95]. This chapter outlines the current HFACS-based approach, including recent implementation updates at NASA Johnson Space Center (JSC). Furthermore, it proposes additional analytical steps to enhance the identification and evaluation of both active and latent failure conditions when applied to specific anomalies or aggregated event data sets.

4.2.2 NASA Human Factors Analysis and Classification System; Current Process

NASA recognized the significance of the work by Wiegmann and Shappell and subsequently established a formal Human Factors Program led by the Safety Culture and Human Factors (SC&HF) Program Manager. This position reports directly to the NASA Office of Safety and Mission Assurance (OSMA) at NASA Headquarters [33] [60] [62] [64] [95]. The Program Manager is typically trained at the doctoral level in psychology and possesses extensive expertise in both aviation and ground-based human factors.

The SC&HF Program Manager serves as the chairperson of the NASAHFACS Task Force, which includes representation from all NASA Centers [104]. Due to their subject matter expertise in the Human Factors Analysis and Classification System (HFACS), the Program Manager is frequently called upon to serve as an expert witness in investigations conducted by NASA, the Federal Aviation Administration (FAA), and the National Transportation Safety Board (NTSB) [105]. The Program Manager is supported by a team of human factors specialists who contribute to the execution and continuous improvement of the Agency's NASAHFACS program.

At the Center level, NASAHFACS responsibilities are typically assigned as collateral duties. However, effective implementation requires formal training, hands-on investigative experience, and sustained engagement with the methodology. The presence of certified NASAHFACS personnel, who are both proficient in the framework and committed to its application, is critical to ensuring analytical rigor and organizational value [66] [95].

Across NASA, all Centers are required to document and submit human factors classifications into an Agency-wide database, enabling enterprise-level tracking and analysis. These data can also be disaggregated to support organization-specific assessments. Because NASA conducts operations in environments not fully addressed by the standard HFACS framework, a modified version, NASAHFACS Version 1.4, was developed and formally approved for Agency use (Figure 64) [106]. This framework closely aligns with the original Wiegmann and Shappell HFACS structure (Figure 61), with the addition of a "Space Environment" sub-tier under "Environmental Factors" [107].

NASAHFACS Version 1.4

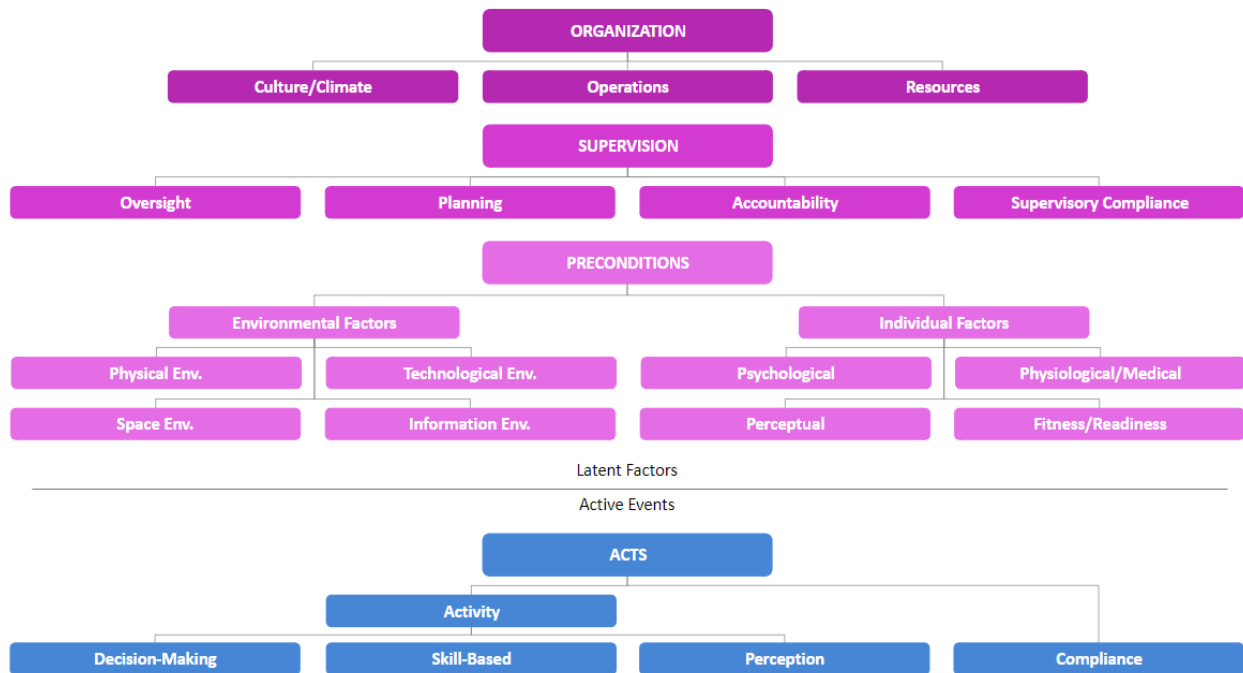


Figure 64. NASAHFACS Framework Version 1.4 [107]

The “Space Environment” sub-tier was introduced following multiple investigations in which existing HFACS nano-codes were insufficient to categorize spaceflight-specific human factors [89]. “Nano-Codes” are the highly specific, granular code classifications used by investigators to identify the precise human behaviors or underlying systemic conditions that cause or contribute to a mishap or incident [108]. The unique operational and physiological conditions associated with spaceflight necessitated the development of additional nano-codes to ensure adequate classification fidelity and traceability [109]. This enhancement was formally implemented as part of the NASAHFACS framework (Figure 65).

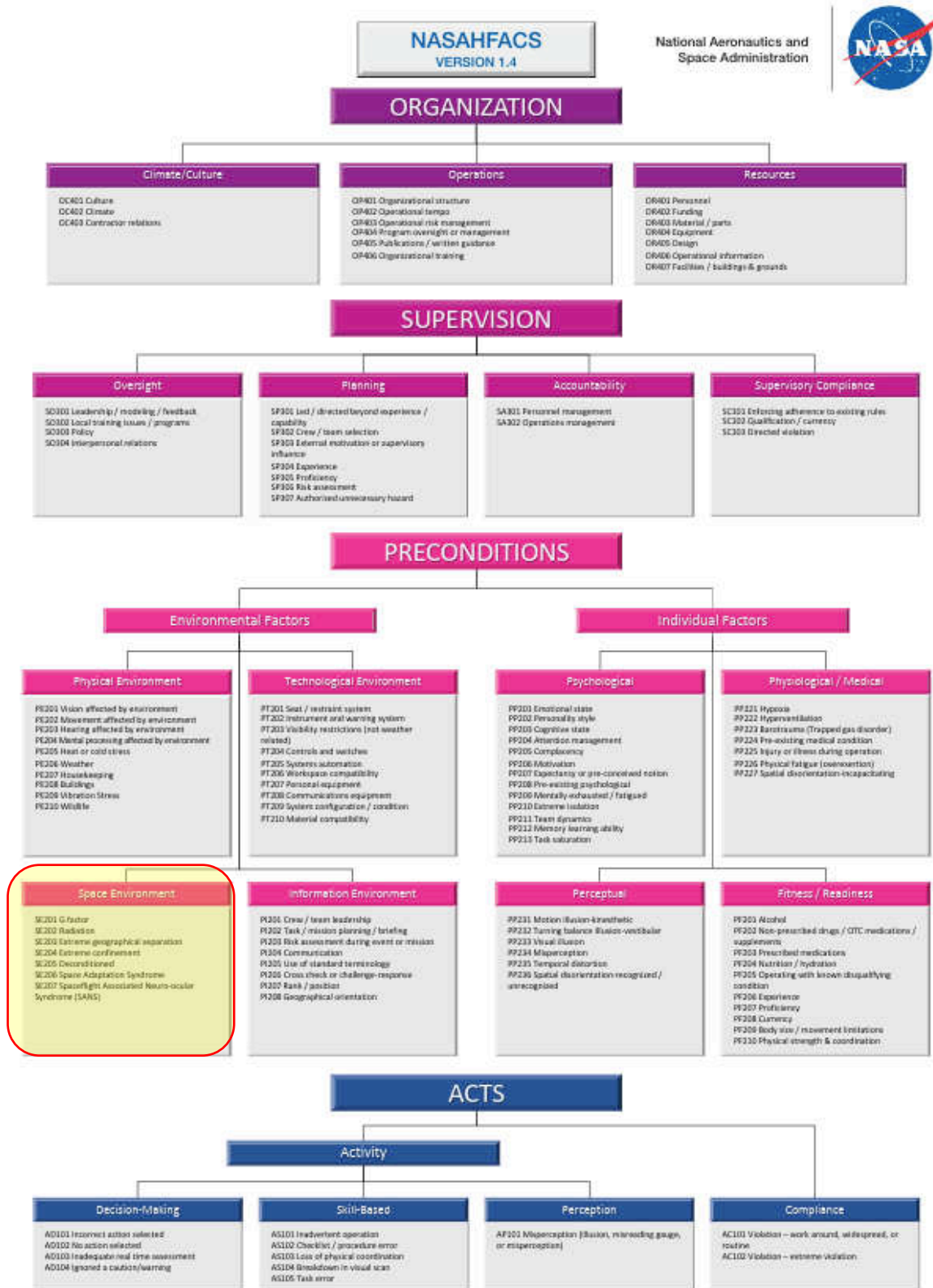


Figure 65. NASAHFACS Spider Chart and Associated Nano-Codes (Version 1.4) [107]

NASA collects and analyzes human factors data derived from NASAHFACS processes and disseminates monthly reports identifying the most prevalent contributing factors, commonly referred to as the “Dirty Dozen” [95]. This practice, also adopted by other government agencies and aviation organizations, highlights the most frequently observed human factor category tiers to support trend analysis and risk mitigation [110]. The “Dirty Dozen” is distributed throughout the organization as part of the Safety Management System (SMS) Promotion pillar, reinforcing safety awareness and proactive risk management. The current NASAHFACS process implemented at NASA Centers other than Johnson Space Center is illustrated in Figure 66. This process categorizes data only to the “category” or “bucket” level and does not extend to the more granular nano-code level.

Current NASAHFACS Process at JSC

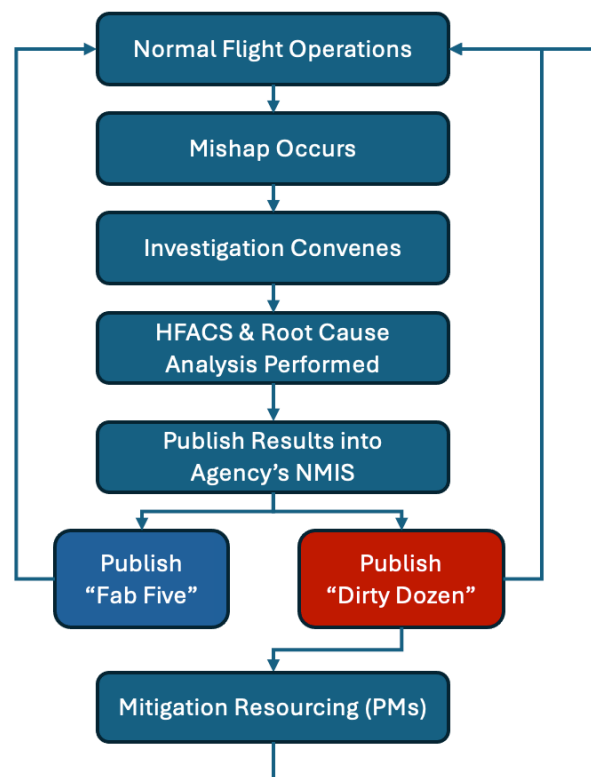


Figure 66. Current NASAHFACS Process at NASA Centers Other than JSC

4.3 NASAHFACS; Proposed Additional Processes

4.3.1 *Establishment of a Local NASAHFACS Committee*

Members of the Johnson Space Center (JSC) Task Force identified the need to establish a formal committee to provide multidisciplinary input during the analysis and classification phases of the NASAHFACS application. Observations indicated that increased participation from personnel with diverse technical and operational backgrounds significantly enhances the quality, consistency, and robustness of classification outcomes. Additionally, the establishment of a local committee enables more frequent and timely reviews of incidents for analysis and classification. Under the existing process external to JSC, reviews typically occur only during major mishaps or annually at the NASA Agency Human Factors Task Force meeting.

To address this gap, eight personnel within the Aircraft Operations Division (AOD) were designated as NASAHFACS-certified members. These individuals represent a broad range of disciplines, including Engineering, Operations, Aircrew, Maintenance, Program Management, and Safety. In addition to core members, visiting participants may be invited to attend committee sessions; however, they are required to complete an introductory NASAHFACS training course prior to participation. This training is available to all NASA employees at no cost as a two-hour, self-paced online course through the SATERN training platform.

A formal organizational structure was developed to clearly define committee roles, responsibilities, and authority, as illustrated in Figure 67. Through the implementation of consistent biweekly meetings, the JSC NASAHFACS Committee conducted over 70 anomaly classifications, spanning a two-year period from retrospective cases to present-day events. This

effort proved highly effective, both in improving classification throughput and in training committee members in the NASAHFACS methodology. Additionally, the committee contributed to populating classification data within the NASA Mishap Information System (NMIS).

To ensure standardization and governance, a JSC NASAHFACS Committee Charter was developed and implemented for all meetings (*Appendix E*). This document provides formal guidance on committee structure, member roles, and procedural execution.

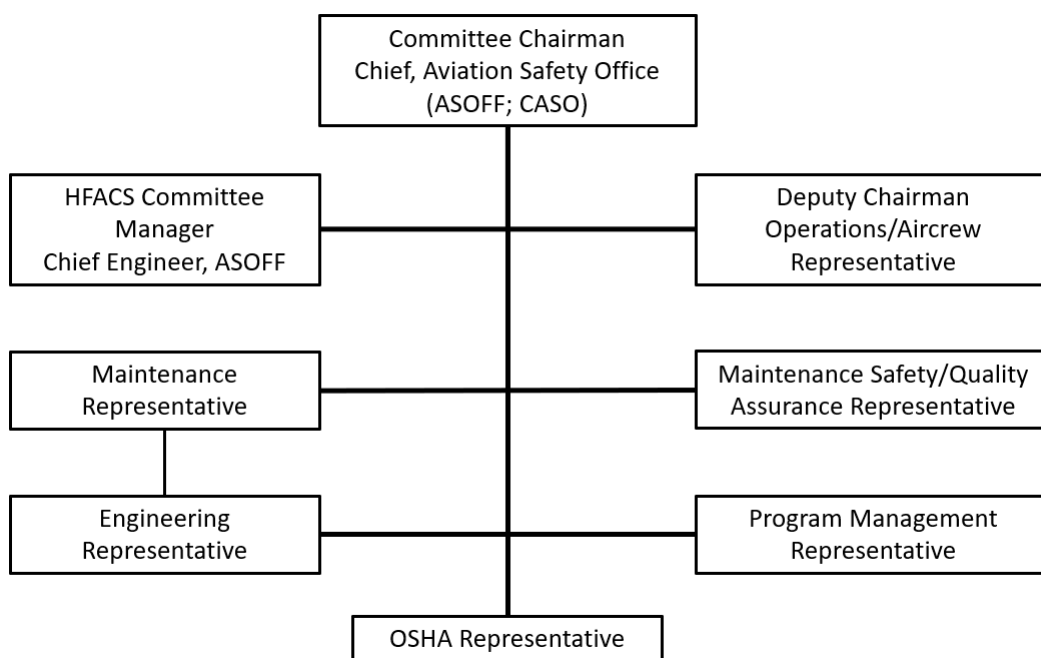


Figure 67. NASA JSC NASAHFACS Committee Organization Structure

4.3.2 JSC NASAHFACS Committee Process

For Type-D mishaps, close calls, and hazard reports, a minimum quorum of three committee members is required to conduct NASAHFACS analysis and classification. For Type-C mishaps and more severe events, a minimum of five members is required.

The Committee Chairperson mandates that the lead investigator for the mishap or close call be present during the committee’s analysis and classification session. Additionally, the

investigation must be at least 95% complete prior to committee review. This requirement ensures that committee members can engage directly with the investigator to obtain clarifications and resolve ambiguities, thereby enhancing analytical accuracy and consistency.

Upon reaching consensus among all participating members, the Committee Chairperson provides formal approval, and all members sign the final classification document. This collaborative approach promotes accountability, ownership, and diligence throughout the process.

Following approval, the finalized nano-code classifications are entered into the Agency's NASA Mishap Information System (NMIS). Once recorded, NASAHFACS specialists can aggregate and analyze the data to generate actionable metrics and insights.

Figure 66 illustrates the current NASAHFACS process utilized at other NASA Centers, while Figure 68 presents the JSC-specific process, along with the proposed standardized framework recommended for adoption across other NASA Centers.

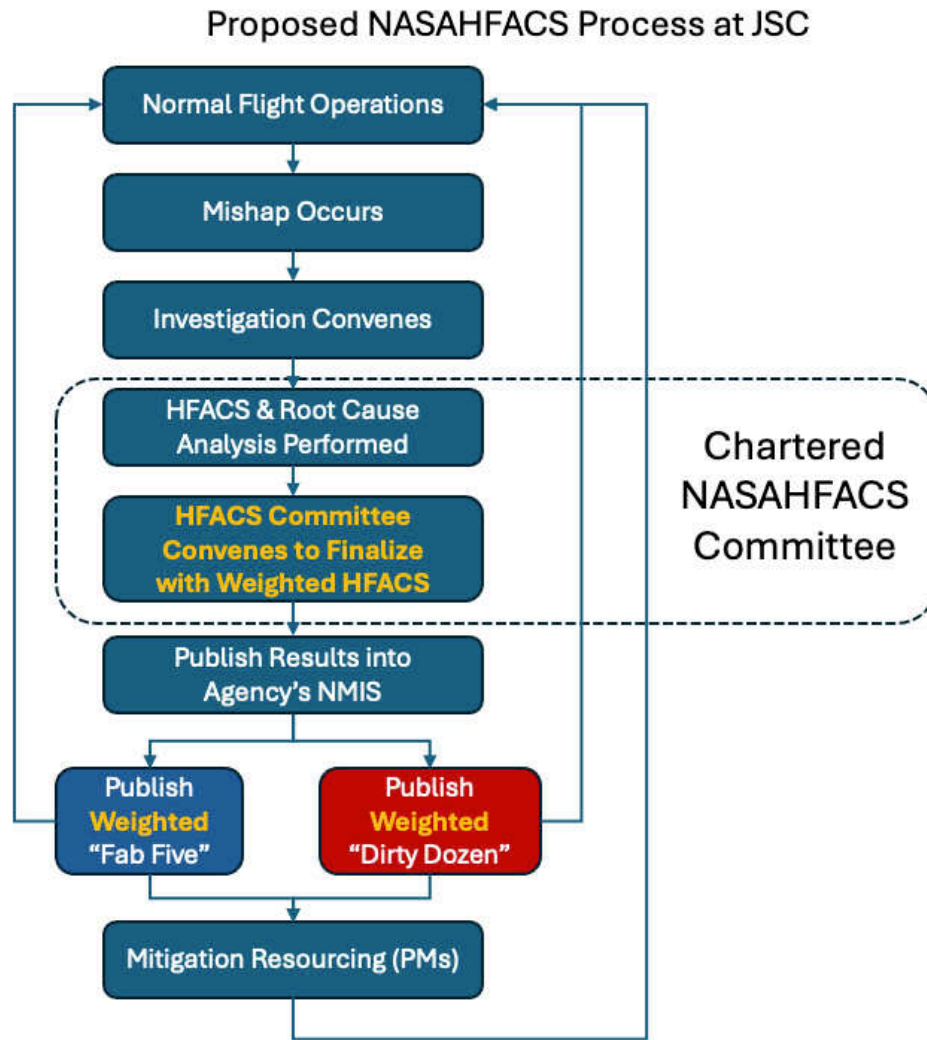


Figure 68. Proposed NASAHFACS Process

4.3.3 *Performing Analytics of Anomalies*

The Agency utilizes Microsoft® Power BI to aggregate and visualize Human Factors Analysis and Classification System (HFACS) metrics. This platform enables dynamic filtering and multi-dimensional analysis, allowing users to tailor data views based on selected criteria. For example, in Figure 69, the dataset is filtered for Johnson Space Center, Fiscal Year 2023, all anomaly types, and flight-related anomalies. The analysis indicates that Decision-Making and Technological Environment are the primary contributing human factors under these conditions.

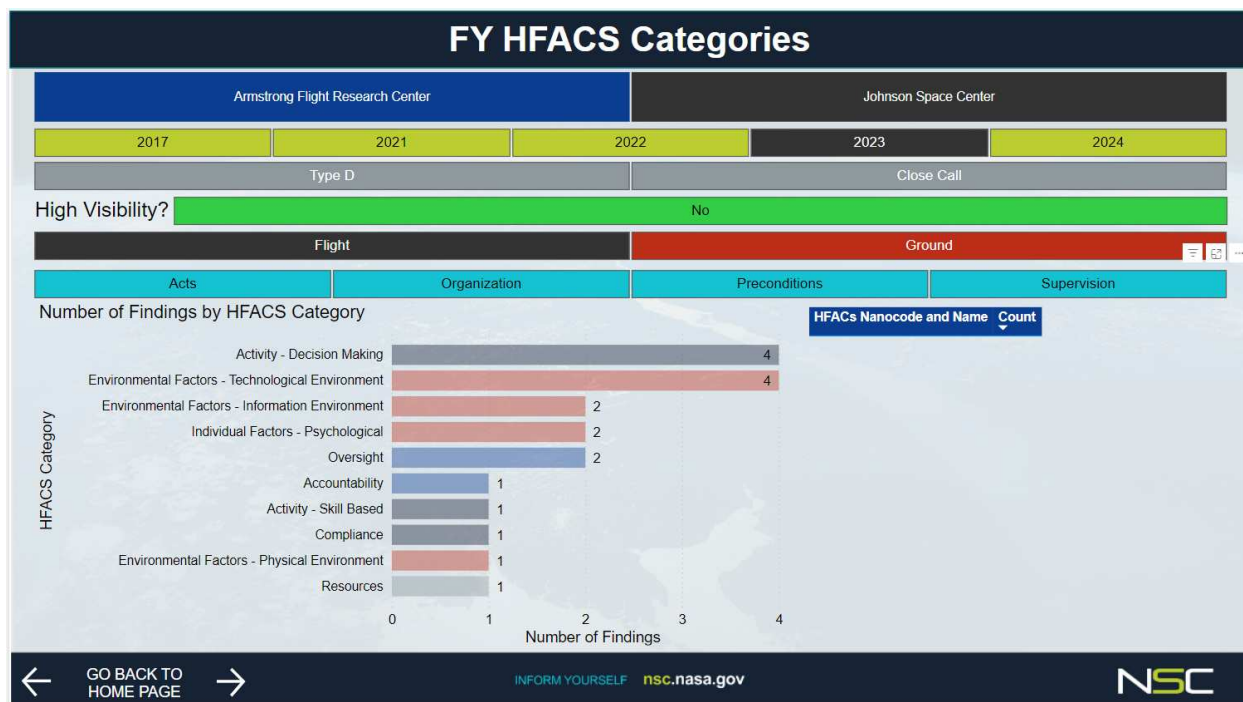


Figure 69. Power-BI Results of 2023/JSC/Flight Anomalies

Similarly, Figure 70 presents a filtered view for Johnson Space Center, Fiscal Year 2023, focusing on Close Calls and Aviation Ground Anomalies. In this case, the dominant contributing human factor is Psychological Preconditions, followed closely by Decision-Making Acts and Skill-Based Errors. These classifications can be further decomposed to examine individual events and their associated “nano-codes,” enabling more granular trend identification.

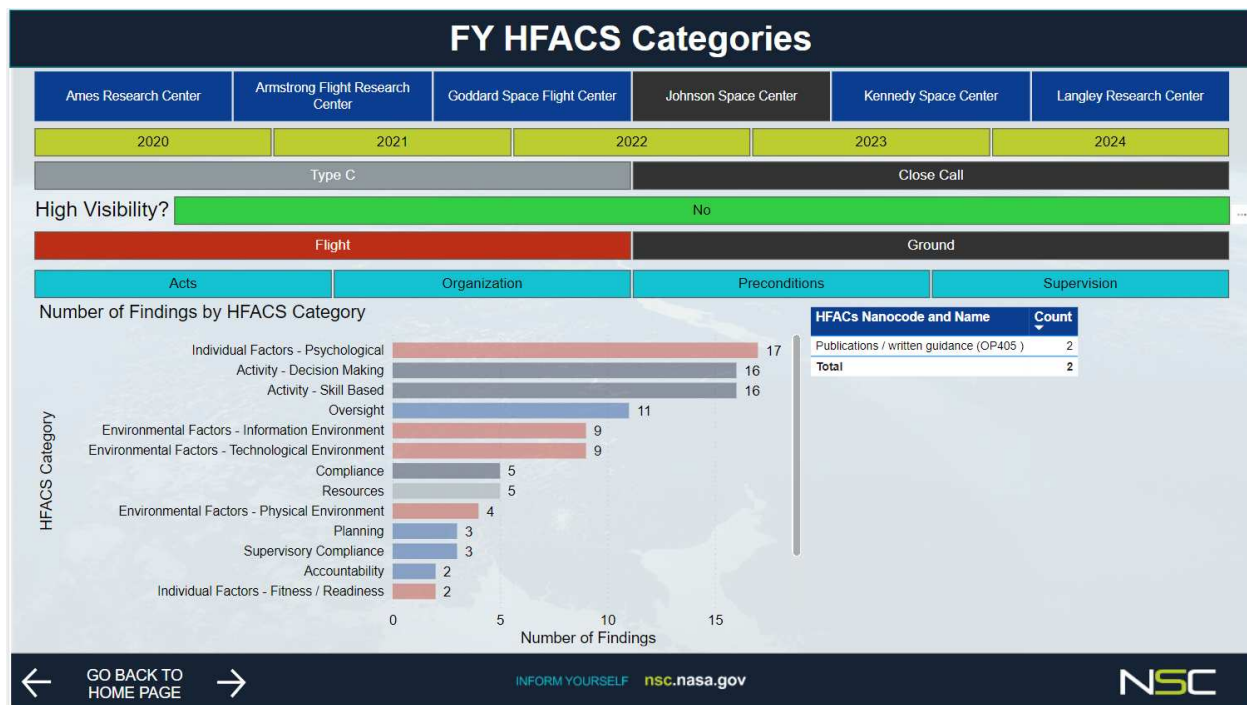


Figure 70. Power-BI Results of 2023/JSC/Aviation Ground/Close Calls Anomalies

Nano-codes represent discrete contributing factors and may vary in their level of influence on a given mishap or close-call event. Their contribution can be characterized as either strong or weak depending on their causal relevance. Furthermore, nano-codes associated with higher-severity outcomes (e.g., Type-C mishaps) should be considered more significant than those linked to lower-severity events such as hazards or close calls. **There is no current process established to capture this metric.**

Now having reviewed the existing NASAHFACS process and the proposed chartered committee, this dissertation can now propose an enhanced analytical approach that incorporates the relative “strength” of each nano-code, both at the individual event level and across aggregated event sets. The initial step involves determining the degree of contribution of each identified nano-code to a specific event. Following completion of the standard NASAHFACS

classification process, a formal review is conducted by the designated committee to assign a contribution level using the NASAHFACS Weighting Chart (Figure 71) [107].

0	Present but not a factor, has potential for future mishaps.
1	Minimal impact on mishap scenario. However, it is a noted departure from processes or procedures.
2	Moderate impact on mishap scenario. It is a departure from process / procedure however its elimination by itself would not have prevented the mishap.
3	Major impact on mishap scenario. Its elimination could have prevented the mishap.
4	Causal impact on mishap scenario. Elimination from mishap chain of events prevents its occurrence.

Figure 71. Published NASAHFACS Weighting Chart [107]

Table 4 further defines the proposed contribution levels, mapping qualitative assessments to quantitative values. This scale ranges from Nil/Present (0.0) to Causal (4.0), with corresponding percentage weightings defined in Figure 71. This structured contribution factor methodology enables more rigorous quantitative analysis of human factors and supports improved identification of systemic trends and risk drivers.

Table 4. Proposed NASAHFACS Contribution Chart/Scale

(NASAHFACS Contribution Chart)	
Contribution Level	Factor
Nil/Present	0
Minimal	1
Moderate	2
Major	3
Causal	4

The assignment of a nano-code contribution factor quantifies the degree to which a given nano-code influences the occurrence of an event. When comparing multiple mishaps and close-call events across a range of anomalies, the severity of resulting damage or injury must also be incorporated into the analysis. In accordance with mishap and close-call categorizations defined in NPR 8621.1D [60], these classifications can be systematically assigned and are summarized in Table 5.

Table 5. Proposed Mishap Severity Factor

Level of Event	Severity Factor
Hazard	0.5
Close Call (Class E)	1
Type-D	2
Type-C	3
Type-B	4
Type-A	5

The nano-code severity factor is defined as the product of the contributory weighting and the event's mishap severity classification. This calculation yields the Proposed Nano-Code Impact Level/Factor, as presented in Table 6.

Table 6. Proposed Nano-Code Impact Level/Factor

		Mishap Severity					
Contribution Level		Hazard	Close Call (Class E)	Type-D	Type-C	Type-B	Type-A
	Value	0.5	1	2	3	4	5
	Nil/Present	0	0	0	0	0	0
	Minimal	1	0.5	1	2	3	4
	Moderate	2	1	2	4	6	8
	Major	3	1.5	3	6	9	12
	Causal	4	2	4	8	12	16

Impact Severe: 10+
Impact Moderate: 4-9
Impact Minor: 0-3

To demonstrate the application of this methodology, a representative dataset consisting of one Type C mishap and three distinct close-call events is evaluated. Event #1 involved a close-call in which aircrew misplaced the landing gear pins and pitot-static covers while operating across three separate airfields. Neither aircrew nor ground personnel were able to recover these items. Under standard procedures, these components are removed during preflight and stored in the refueling access panel on the underside of the T-38N aircraft. Proper preflight procedures require verification that these items are accounted for prior to flight.

Event #2 represents a similar occurrence, where the same equipment was not recovered following flight operations. However, the subsequent investigation identified a different set of contributing human factors. Event #3 involved multiple latent conditions and active human-factor-related failures, culminating in a close call when a WB-57 aircraft wing was inadvertently towed into a chain-link fence. Event #4 represents a more common but costly anomaly in which

a bird strike resulted in engine ingestion, producing a Type C mishap classification. Each of these events is analyzed individually, after which the Nano-Code Impact Factor (Table 6) is applied to enable comparative analysis across anomalies within the organization.

The proposed framework enables the NASAHFACS Committee to systematically evaluate each event and assign weighted values (Table 4) to the relevant nano-codes. This structured approach facilitates the identification of key performance metrics and systemic vulnerabilities. Aggregating weight values across categories, tiers, and sub-tiers allows for the prioritization of mitigation efforts and the identification of areas requiring managerial or resource intervention.

For example, analysis of Event #1 (Figure 72 and Table 7) indicates that the primary contributing nano-codes were AC101 Violation (Work Around) and AS102 Checklist/Procedural Error, each exerting approximately equal influence on the undesired outcome. Accordingly, mitigation strategies should prioritize strengthening procedural compliance and enhancing personnel training to reduce rule deviations and improve task execution.

In contrast, although Event #2 resulted in a similar undesired operational outcome, it produced a distinctly different HFACS profile (Figure 73). As presented in the figure and in Table 7, the primary contributing nano-codes were AS102: Checklist/Procedural Error and Task Saturation. Application of the revised impact classification enables the development of more targeted mitigation strategies, with priority given to checklist discipline training, followed by efforts to reduce operational tempo to better manage task saturation. Furthermore, because AS102: Checklist/Procedural Error is a common contributing factor in both Events 1 and 2 and carries the highest impact rating in each case, mitigation efforts should emphasize focused training on procedural compliance and checklist discipline as a primary corrective action.

T-38N Missing Landing Gear Pins Postflight #1 (Impact Nano-Codes)

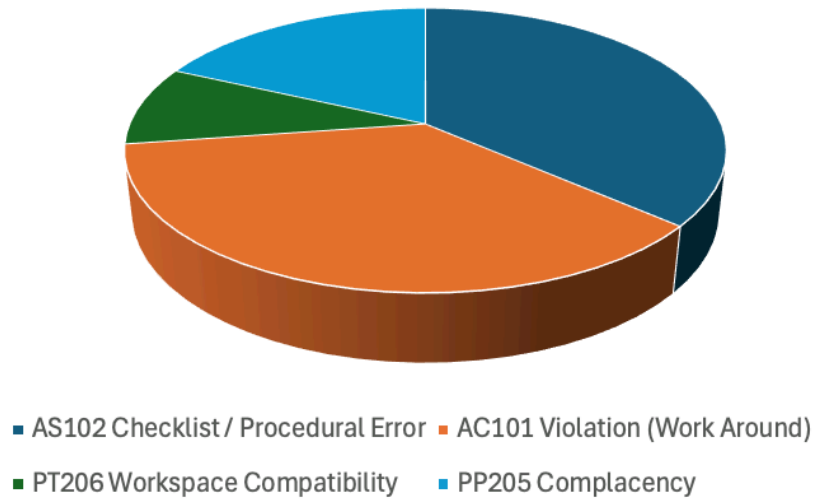


Figure 72. Impact Nano-Code Distribution of Event 1

T-38N Missing Landing Gear Pins Postflight #2 (Impact Nano-Codes)

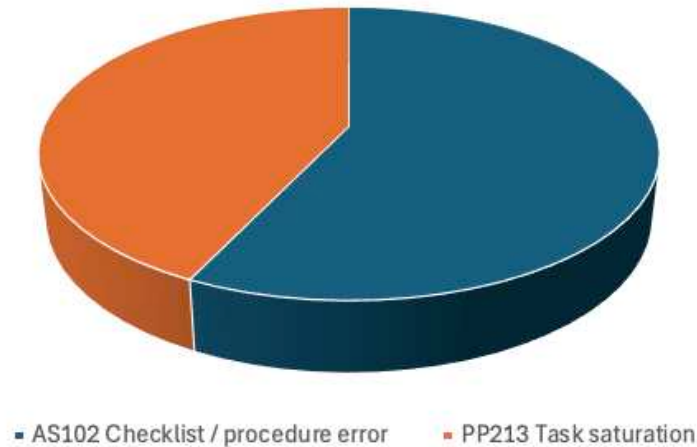


Figure 73. Impact Nano-Code Distribution of Event 2

Event #3, WB-57 Wingtip Contacts Fence, contains multiple nano-codes and is more effectively represented using a column graph rather than a pie chart. As illustrated in Figure 74, AD102 – No Action Selected yielded the highest impact score, indicating a need for targeted

training to encourage personnel to actively voice concerns when operational conditions or circumstances appear unsafe or inconsistent. Tied for the second-highest impact scores were PI201 Crew/Team Leadership and PI204 Communication, suggesting opportunities for enhanced leadership development and improved communication practices. Additionally, the evaluation of alternative communication technologies may further strengthen operational effectiveness and reduce the likelihood of similar events.

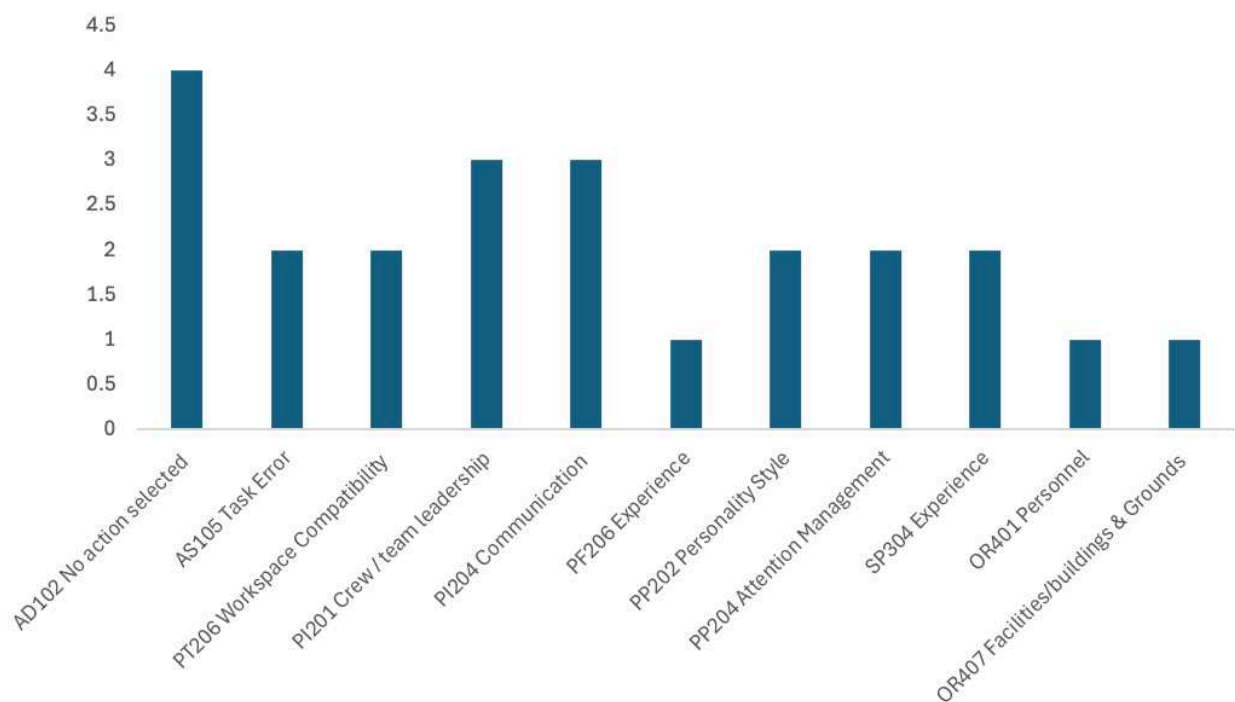


Figure 74. Impact Nano-Code Distribution of Event 3

Table 7. Example Analysis of Proposed NASAHFACS Impact Nano-Code Values

	Description	Category	Nano-Code	Contribution Level	Mishap Severity	Impact Level
Event 1	T-38N Missing Landing Gear Pins postflight #1	Skill-Based	AS102 Checklist / Procedural Error	Causal	Close Call	4
		Compliance	AC101 Violation (Work Around)	Causal		4
		Technological	PT206 Workspace Compatibility	Minimal		1
		Psychological	PP205 Complacency	Moderate		2
Event 2	T-38N Missing Landing Gear Pins Postflight #2	Skill-Based	AS102 Checklist / procedure error	Causal	Close Call	4
		Psychological	PP213 Task saturation	Major		3
Event 3	WB-57 Wingtip Fence	Decision Making	AD102 No action selected	Causal	Close Call	4
		Skill-Based	AS105 Task Error	Moderate		2
		Technological	PT206 Workspace Compatibility	Moderate		2
		Information	PI201 Crew / team leadership	Major		3
		Information	PI204 Communication	Major		3
		Fitness/Readiness	PF206 Experience	Minimal		1
		Psychological	PP202 Personality Style	Moderate		2
		Psychological	PP204 Attention Management	Moderate		2
		Planning	SP304 Experience	Moderate		2
		Resources	OR401 Personnel	Minimal		1
		Resources	OR407 Facilities/buildings & Grounds	Minimal		1
Event 4	T-38N Birdstrike Engine Ingestion	Decision-Making	AD104 Ignored a caution/warning	Moderate	Type-C	6
		Physical Environment	PE210: Wildlife	Causal		12

To visualize the impact of individual events on the overall event set, the nano-code impact factors are superimposed onto Table 6 using the comprehensive event assessments provided in Table 8. Each event is identified by its corresponding numerical designation as defined in Table 7. The analysis indicates that the only “red” (i.e., severe) nano-code impact is associated with PE210: Wildlife. Based on this finding, management should prioritize investment in technologies and mitigation strategies aimed at reducing the likelihood of wildlife-related hazards, such as bird strikes and engine ingestion events. The most severe event is illustrated in Figure 75.

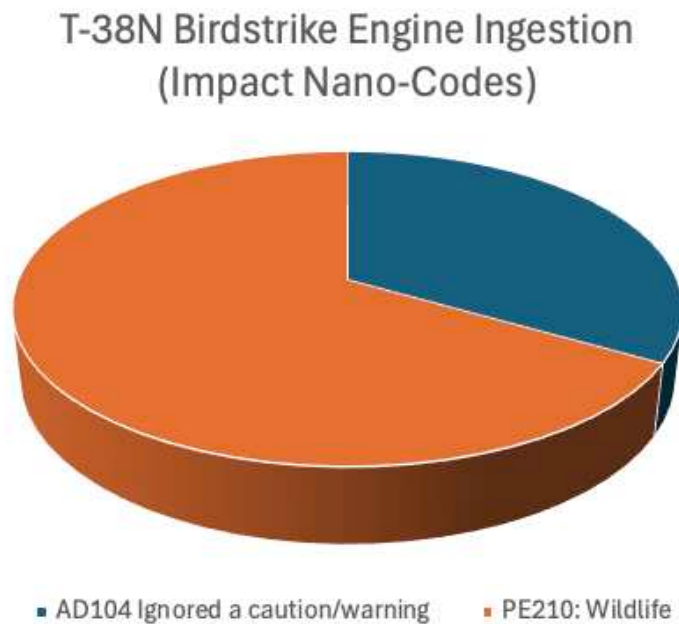


Figure 75. Impact Nano-Code Distribution of Event 4

Table 8. Example Overlay of Four Events for Comparison

		Mishap Severity					
		Close Call					
		Hazard	(Class E)	Type-D	Type-C	Type-B	Type-A
Contribution Level	Value	0.5	1	2	3	4	5
	Nil/Present	0	0	0	0	0	0
	Minimal	1	0.5	1	2	3	4
	Moderate	2	1	2	4	6	8
	Major	3	1.5	3	6	9	12
	Causal	4	2	4	8	12	16
		Impact Severe: 10+					
		Impact Moderate: 4-9					
		Impact Minor: 0-3					
		Event #					

The next most severe nano-code impact is AD104: Ignored a Caution/Warning, which originates from the same event. This highlights a critical human factors concern. Accordingly, emphasis should be placed on enhancing operator training to reinforce adherence to established operational procedures and ensure that warnings, particularly those related to wildlife activity, are neither dismissed nor overlooked.

Table 9 presents the resulting “Impact Derived” Nano-Code Dirty Dozen for the four examples previously analyzed. Because this analysis incorporates impact derived nano-codes, it is advantageous to construct the Dirty Dozen by ranking nano-codes from highest to lowest severity. In cases where impact factors are totaled as equivalent to each other, prioritization should be determined based on frequency of occurrence, with greater weight assigned to nano-codes exhibiting higher recurrence across multiple modes.

Table 9. Impact Derived Nano-Code Dirty Dozen

Ranking	Severity	Nano-Code
1	12	PE210: Wildlife
2	8	AS102: Checklist/Procedural Error (x2 combined; 4 each)
3	6	AD104: Ignored a caution/warning
4	4	AC101: Violation (Work Around)
5	4	AD102: No Action Selected
6	3	PP213: Task Saturation
7	3	PI201: Crew/Team Leadership
8	3	PI204: Communications
9	2	PI205: Complacency
10	2	AS105: Task Error
11	2	PT206: Workspace Compatibility
12	2	PP204: Attention Management

4.4 Chapter Summary

“Safety First. Safety Always” is a common workplace mantra promoting safety. Many companies and organizations have adopted this statement. The Occupational Safety and Health Administration considers safety as a “Core Value” [111]. Having a structured safety process established and making the safety team feel empowered and that their actions becoming beneficial are key. Using excess resources through optimizing an organization’s effectiveness to bring those safety processes to fruition should be a goal of managers.

In this chapter, the current NASAHFACS process at all other NASA Centers were covered. At Johnson Space Center, extra processes were implemented to investigate, classify, and analyze human factors that contribute to hazards, close calls, and mishaps. Establishing a chartered NASAHFACS committee, training the members, document the results and enjoy everyone’s commitment to providing accurate data to be used locally and at the NASA Agency level or Enterprise Level. Furthermore, this research introduced and implemented a novel methodology to identify, quantify, and assess the impacts of individual NASAHFACS “nano-codes” contributing to operational events, representing a significant advancement in human factors analysis and risk mitigation.

CHAPTER 5: SUMMARY, CONCLUSIONS, AND CONTRIBUTIONS

5.1 Summary and Conclusions

This dissertation addressed a critical capability gap in government aircraft operations: the absence of an integrated analytical tool capable of dynamically optimizing operational, financial, and safety-related decisions in complex aviation environments. Aircraft operations organizations operate under significant uncertainty driven by fluctuating demand, budgetary limitations, workforce constraints, evolving mission requirements, and external disruptions such as inflation, fuel price volatility, and pandemics. Existing management tools, including scheduling and spreadsheet-based software, provide limited capability for integrating operational, financial, and scheduling variables into a unified decision-making framework. Consequently, aviation leaders are often required to make time-sensitive decisions with incomplete visibility into downstream organizational effects.

To address this problem, this research developed and validated a novel system dynamics model to support scenario-based optimization within government aircraft operations, specifically the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) Aircraft Operations Division (AOD). To the best of the author's knowledge, this research represents the first application of system dynamics modeling to government aircraft operations at this level of fidelity. Extensive data collection and analysis were performed within AOD, and the resulting model was validated and verified through stakeholder interviews, operational and financial benchmarking, three Delphi Committee reviews, and annual reports.

A fundamental contribution of this research was the development of a mathematical framework to define organizational Value within an aircraft operations environment. This

framework established a novel top-level valuation equation that served as the foundation of the system dynamics model and provided a scalable methodology for quantifying organizational performance. Unlike traditional approaches that focus narrowly on availability, reliability, or scheduling, the developed framework integrates operational, financial, staffing, and safety considerations into a unified decision-support system. Furthermore, the model architecture is sufficiently adaptable for application beyond government aviation to analogous systems, including commercial aviation, nonprofit organizations, financial institutions, households, and other complex operational enterprises.

Following development of the top-level model, subordinate model tiers were constructed to reflect the organizational structure, operational requirements, and regulatory guidance governing NASA aircraft operations. The modular, open-architecture design enabled controlled variation of critical operational parameters, including personnel salaries, staffing levels, customer billing rates, fuel costs, and mission demand variables. Through an integrated dashboard interface, decision-makers can assess organizational impacts and evaluate alternative courses of action in near-real time. The model demonstrated strong utility as a proactive decision-support capability capable of projecting future operational conditions and informing strategic decisions before adverse consequences occur.

The validated useful and verified sufficiently accurate system dynamics model was subsequently applied to a range of representative and extreme operational scenarios to evaluate its utility and versatility. These scenarios included increased jet fuel prices, pandemic-related disruptions, reductions in operational tempo, and budgetary reductions commonly experienced by aviation organizations. To replicate real-world conditions observed during this research, a pandemic trigger function was incorporated into the model to simulate COVID-19-related

disruptions experienced within AOD. This enhancement further demonstrated the model's ability to predict and evaluate future pandemic-like or catastrophic events affecting flight operations.

Scenario-based optimization demonstrated measurable operational benefits and validated the model's effectiveness as a decision-support tool. An increase in jet fuel prices resulted in a projected cumulative financial deficit of approximately \$4.29M USD over a three-fiscal-year period. However, a modest reduction in average monthly flight hours enabled the organization to achieve a net-zero financial balance by the end of each fiscal year. As an alternative mitigation strategy, adjusting the customer billing multiplier also offset the increased operational costs and restored a net-zero financial position within a single fiscal year. These findings provide decision-makers with two viable approaches for managing budget expenditures while maintaining organizational objectives throughout the planning horizon. Collectively, the results demonstrate the capability of system dynamics modeling to evaluate competing alternatives, optimize resource allocation, and support informed decision-making in response to dynamic operational and financial conditions.

A significant contribution of this dissertation was the integration of organizational optimization with safety enhancement initiatives. Findings demonstrated that efficiencies gained through system dynamics-driven optimization can enable the strategic reallocation of resources toward safety and risk mitigation programs. This research expanded NASA's Human Factors Analysis and Classification System (NASAHFACS) process through the incorporation of quantitative, impact-based human factors nano-codes. This advancement established a structured methodology for prioritizing mitigation strategies, resource allocation, mishap prevention, and operational risk reduction based on measurable impact values rather than qualitative assessment alone. Additional recommendations included the establishment of localized NASAHFACS

chartered committees, formalized training, and standardized documentation practices to strengthen safety analysis at both Center and Agency levels.

At the enterprise level, NASA provides overarching governance for aircraft operations through funding allocation and program oversight. Although enterprise-level optimization was beyond the scope of this dissertation, the developed architecture supports future integration of center-level models into a comprehensive NASA Aircraft Operations Enterprise Model. Such a capability could improve Agency-level forecasting, scenario planning, budget optimization, and strategic decision-making across NASA flight operations centers. Moreover, the adaptability of the proposed methodology enables broader application to high-volume commercial airlines, military organizations, and other aviation-related enterprises where dynamic operational uncertainty exists.

Ultimately, this dissertation demonstrates that integrating system dynamics modeling with human factors analysis provides a practical and innovative approach for transforming aviation decision-making from reactive, experience-based judgment to deliberate, data-informed, and proactive organizational management. The methodologies developed herein establish a scalable framework for enhancing operational effectiveness, improving safety performance, optimizing resource utilization, reducing costs, and strengthening long-term organizational resilience and mission success.

5.2 Significant Contributions

Several significant contributions emerged from this research. First, a robust mathematical framework was developed to quantify organizational value at an unprecedented level of granularity within government aviation operations. The flexibility and scalability of this

framework extend well beyond government applications, enabling adaptation to analogous operational environments, including commercial aviation enterprises, private industry, small businesses, households, and individual financial or operational systems. Consequently, the methodology provides a transferable decision-support capability applicable across a broad range of organizational contexts.

Second, a comprehensive system dynamics model of a government aviation organization was developed, representing a capability not previously identified in the existing body of literature. This research established a novel analytical framework for modeling the complex interdependencies among operational, financial, and human performance variables within a government aviation organization, thereby advancing the application of system dynamics to aircraft operations management.

Furthermore, this research demonstrated that optimization of government aviation operations can directly enhance both operational efficiency and organizational safety through more effective and efficient allocation of resources toward mishap mitigation and prevention initiatives. A particularly innovative contribution of this dissertation was the integration of quantitative impact values assigned to human factors nano-codes within the NASA Human Factors Analysis and Classification System (NASAHFACS) process. This advancement introduces a data-driven methodology for prioritizing resource allocation, mishap prevention strategies, and operational risk mitigation efforts, thereby strengthening organizational decision-making and improving safety outcomes.

The implementation of the methodologies developed in this dissertation provides organizations with a structured and analytically rigorous approach to improving resource efficiency, enhancing safety performance, and optimizing operational effectiveness. Ultimately,

these capabilities support the achievement of organizational and financial objectives while contributing to mission success, the preservation of human life, and the protection of critical assets.

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APPENDIX A: SYSTEM DYNAMICS MODEL ASSUMPTIONS OF KEY INPUTS

No.	Tier Level/Metric	Description / Metric Value
1.	ALL	The system dynamics model is based on mostly linear inputs but initiating at different times and triggers
2.	ALL	Time Horizon is 36 months in duration but adjustable. Time-step is 0.25 months.
3.	ALL	The start of the Time Horizon begins on Oct 1 st and corresponds to the beginning of the fiscal year
4.	ALL	Allocated funding for that fiscal year is fully awarded at the beginning of month 2 (November)
5.	ALL	Allocated PPBE funding is awarded in one lump sum at the beginning of month 2 of that fiscal year
6.	ALL	Baseline metrics set costs for fuel, POL, wages,
7.*	Reimbursable Revenue Funds	Based on actual mission costs and flight hours flown.
8.*	SFCO (Space Flight Crew Operations) And HEO (Human Explorations and Operations)	SFCO funds represent the primary government Planning, Programming, Budgeting, and Execution (PPBE) funding source utilized throughout this dissertation. These funds are determined based on actual mission requirements, operational costs, and annual flight hours, typically ranging from \$30 million to \$70 million per fiscal year. For consistency, this dissertation assumes that Human Exploration and Operations (HEO) funds and Space Flight Crew Operations (SFCO) funds are synonymous. It should be noted that NASA organizational nomenclature evolved since the completion of this research. In September 2021, NASA reorganized the Human Exploration and Operations Mission Directorate (HEOMD) into two separate organizations: the Space Operations Mission Directorate (SOMD) and the Exploration Systems Development Mission Directorate (ESDMD). Subsequently, in May 2026, SOMD and ESDMD were recombined to form the Human Spaceflight Mission Directorate (HSMD). Accordingly, references to HEOMD, SOMD, and HSMD within this dissertation should be interpreted as representing the same overarching mission directorate at different points in time.

9.	Fixed Cost (Expense)	Combined operating costs with no flight hours flown
10.	Variable Cost (Expense)	Costs associated with flying mission and training
11.	GV Maint Cost/FltHr (Variable Expense)	\$8,000 per Flt Hr Flown
12.	GIII Maint Cost/FltHr (Variable Expense)	\$5,000 per Flt Hr Flown
13.	WB-57 Maint Cost/FltHr (Variable Expense)	\$8,000 per Flt Hr Flown
14.	T-38(N) Maint Cost/FltHr (Variable Expense)	\$6,500 per Flt Hr Flown
15.	SGT Maint Cost/FltHr (Variable Expense)	\$8,000 per Flt Hr Flown
16.	GV Initial Value	\$17M
17.	GV Salvage Value	\$1.5M
18.	GV Lifespan	25 years (300 months)
19.	GIII Initial Value	\$4M
20.	GIII Salvage Value	\$500k
21.	GIII Lifespan	6 years (72 months)
22.	WB-57 Initial Value	\$5M
23.	WB-57 Salvage Value	\$1.5M
24.	WB-57 Lifespan	15 years (180 months)
25.	T-38(N) Initial Value	\$6M
26.	T-38(N) Salvage Value	\$5M
27.	T-38(N) Lifespan	10 years (120 months)
28.	SGT Initial Value	\$2M
29.	SGT Salvage Value	\$1M
30.	SGT Lifespan	5 years (60 months)

31.	Admin Equip Initial Value	\$1M
32.	Ellington Facility Initial Value	\$3M
33.	El Paso Facility Initial Value	\$3M
34.	Support Equipment Initial Value	\$1M
35.*	GV Charge to Customer per Flt Hr	\$3,500 per Flt Hr
36.*	GIII Charge to Customer per Flt Hr	\$3,000 per Flt Hr
37.*	WB-57 Charge to Customer per Flt Hr	\$7,000 per Flt Hr
38.	T-38(N) Charge to Customer per Flt Hr	No charge to customer since SFCO funding coverage is direct
39.*	SGT Charge to Customer per Flt Hr	\$5,000 per Flt Hr
40.	# of GV Aircraft	1
41.	# of GIII Aircraft	1
42.	# of WB-57 Aircraft	3
43.	# of T-38(N) Aircraft	20
44.	# of SGT Aircraft	1
45.*	Average Salary/Wage per hour per person	\$31/hr
46.*	# of personnel at AOD	285 people
47.	GV Fuel Burn	1,000 gallons per Flt Hr
48.	GIII Fuel Burn	600 gallons per Flt Hr
49.	WB-57 Fuel Burn	600 gallons per Flt Hr
50.	T-38(N) Fuel Burn	375 gallons per Flt Hr
51.	SGT Fuel Burn	400 gallons per Flt Hr
52.*	# of Aircrew	12

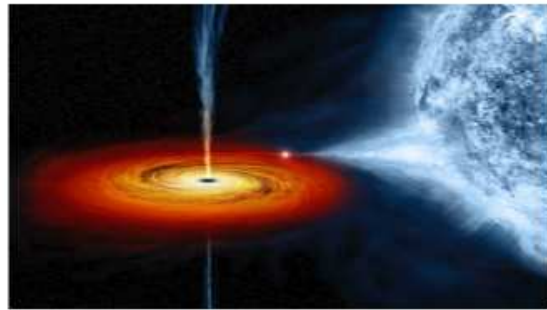
53.	Training Cost to Aircrew	\$60k per year average (\$5k/mo each)
54.	Baseline Utilities per month (Fixed)	\$15,000 per month
55.	Variable Utilities per month (Variable)	Total Flight Hours Flown per Month * \$60 per Ft Hr
56.	PPBE Annual Budget (range only)	\$50M-\$75M per fiscal year
57.*	Fuel Cost (avg.)	\$5 per gallon
58.	Inflation	3.3% increase per year
59.	Cost of Living Adjustment (COLA)	3.3% increase per year
60.	Parts on the shelf (initial)	\$4M USD
61.	Initial Standup Investment	\$0 USD
62.*	# GS Personnel (Each FY)	35
63.*	# CS Personnel (Each FY)	238
64.*	GS Avg Hourly Wage	\$47.00 (FY1), \$48.55 (FY2), \$50.15 (FY3)
65.*	CS Avg Hourly Wage	\$29.00 (FY1), \$29.96 (FY2), \$30.95 (FY3)
66.*	Pilot Avg Hourly Wage	\$85.00 (FY1), \$87.81 (FY2), \$90.70 (FY3)
67.*	Overtime Normal Ops	5%
68.*	Safety Initiatives	\$25k per FY
69.*	Average T-38N Flight Hours per month	215
70.*	Normal Ops Balanced SFCO FY1	\$45.0M USD
71.*	Normal Ops Balanced SFCO FY2	\$45.8M USD
72.*	Normal Ops Balanced SFCO FY3	\$47.4M USD
73.*	ABoVE Mission Hours	75 hours every year in the fall
74.*	DeltaX Mission Hours	83 hours every year in the spring

75.*	Oil Spill Mission Hours	15 hours every year in the summer
76.*	LVIS Mission Hours	57 hours every year in the late spring
77.*	SnowEx Mission Hours	95 hours every year in the winter
78.*	SWOT Mission Hours	120 hours only once in FY2
79.	USNTPS Depot Overhauls	\$700k every 6 months
80.	USAF Depot Overhauls	\$700k every 6 months
81.	Commercial Crew Program Tax	9.85%
82.	DoD/DoW Tax	9.85%
83.	GIII Direct Return	Twice Per year (Support GV)
84.	GV Direct Return	Kazakhstan Direct Return (twice per year)
85.	GV Soyuz Launch Support	Star City (twice per year)
86.	Starliner Domestic Direct Return	Twice per year (GIII and GV)
87.	SpaceX Domestic Direct Return	Twice per year (GIII and GV)
88.	SGT Artemis Support	Every 3 months
89.	WB-57 Launch Support (Starliner and SpaceX)	Six times per year (includes cargo resupply)
90.	WB-57 Landing Support (Starliner and SpaceX)	Six times per year (includes cargo resupply)
91.	Time Horizon	36 months
92.	Time Step	0.25 months
		NOTE: * Denotes identified metric to vary

APPENDIX B: MODELING ANALYSIS AND OPTIMIZATION OF ENGR-532
(PARTICIPATION PRESENTATION TO ENGR-532, DYNAMICS OF COMPLEX
ENGINEERING SYSTEMS)

On November 1st of 2016, as part of the ENGR/SYSE-532 course requirements, Trent Kingery presented this presentation on “retaining student knowledge” using various syllabus techniques. This system dynamics model captured a unique “non-material” system, the learning and retention of knowledge, by using statistical data of documented learning and memory retention studies. Not only does this unique approach of optimizing syllabus techniques benefit student progress throughout the semester, but it demonstrates the flexibility of using VensimPLP® to model non-material systems such as thoughts and memory.

Modeling Analysis and Optimization of ENGR-532



ENGR-532 PARTICIPATION PRESENTATION

TRENT KINGERY

NOVEMBER 1ST, 2016

1

Problem Statement

- The current ENGR-532 syllabus is designed to include heavy reading volumes to teach a student to learn ways of processing huge amounts of data quickly.
- The analysis presented in this brief uses the skills learned in ENGR-532 to first model the current syllabus and then provide data and optimization options to determine if this is efficient.
- A recommendation will be presented based on the results.

November 1, 2016

Modeling Analysis and Optimization of ENGR-532

2

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Assumptions

- Learning (information retention) efficiencies (see refs):
 - Lecture Learning Retention: 5%
 - Reading Learning Retention: 10%
 - Assignment & Project Learning Retention: 75%
- Memory Loss (long and short term): 20% of the total Knowledge
- Student Reading Rate: 7 minutes per page
- Student Learning Efficiency: 1.0 (only for use with distractions, external factors, or handicap compensation)
- Used 4:1 Rule of Thumb (ROT) for this course load (4 hours of outside class for every 1 SH course)

(refs: www.timelessinformation.com and <https://www.washingtonpost.com/news/answer-sheet/wp/2013/03/06/why-the-learning-pyramid-is-wrong/>)

November 1, 2016

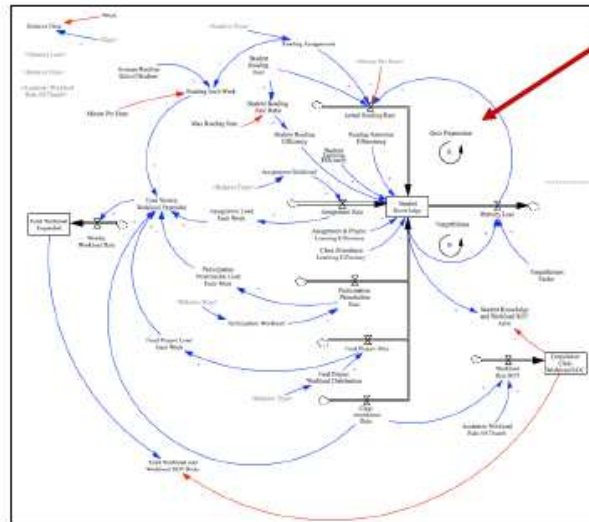
Modeling Analysis and Optimization of ENGR-532

3

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Model

- Model Check 'OK'
- Unit Check 'OK'
- Time Horizon: 15 Weeks
- Time Step: 0.5 Weeks
- Units for Time: Weeks
- Units for Knowledge: Hours
- Feedback Loops: 2
 - R: Quiz Preparation
 - B: Forgetfulness
- Stocks: 3
 - Student Knowledge
 - Total Workload Expended
 - Cumulative Class Workload ROT



November 1, 2016

Modeling Analysis and Optimization of ENGR-532

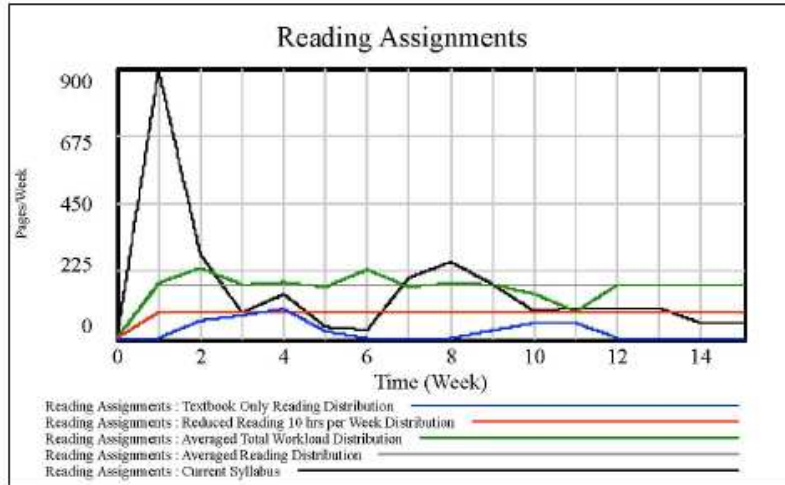
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4

Variable (Reading Assignments)

Five Scenarios:

1. Current Syllabus
2. Averaged Distribution of the current Syllabus
3. Averaged Total Workload Distribution
4. 10 hours/week Reading Distribution
5. Textbook ONLY Reading Requirement



November 1, 2016

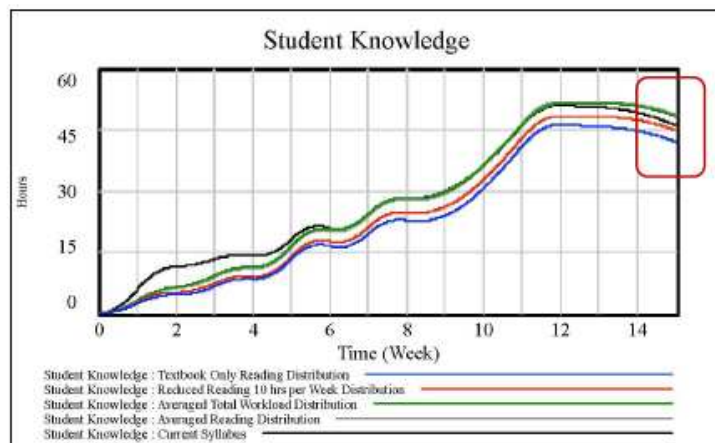
Modeling Analysis and Optimization of ENGR-532

5

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Effects on Student Knowledge

- The current syllabus has an end result similar to assigning 10 hours per week of reading material.
- The end result range between all five scenarios is less than 8 hours of knowledge difference (un-gained/lost knowledge).
- The best option for Student Knowledge is to keep same workload, but redistribute across to have the Total overall workload distributed across the semester.
- Reduction in required reading may produce major benefits if substituted with stand alone modeling project, since learning on projects is much higher than reading.



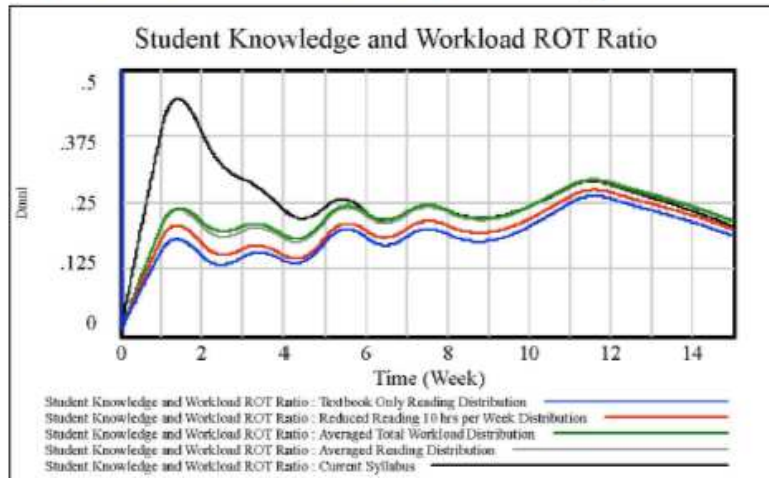
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Effects on Student Knowledge



November 1, 2016

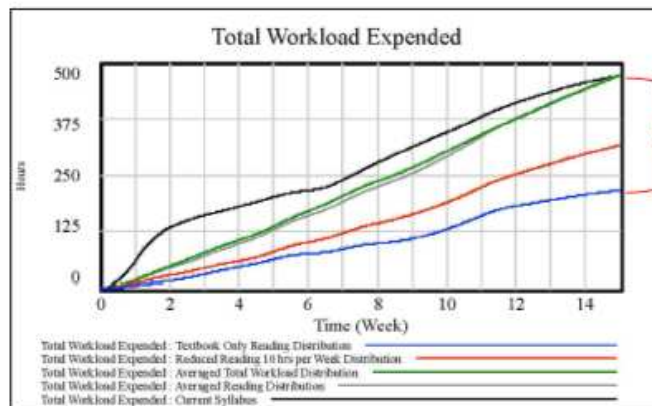
Modeling Analysis and Optimization of ENGR-532

7

7

Levels of Effort

- Major differences in required effort by the various scenarios.
- When compared to the Student Knowledge, the knowledge gained per workload expended shows that the current syllabus, whether kept same or redistributed, is not efficient.



November 1, 2016

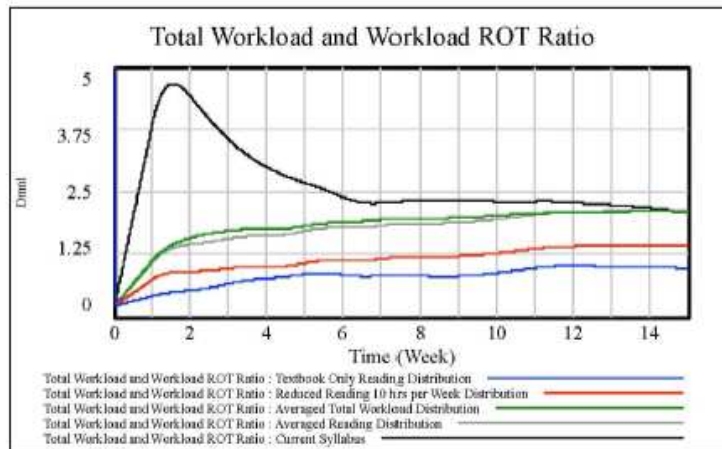
Modeling Analysis and Optimization of ENGR-532

8

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Levels of Effort

- A value of 1.0 identifies the course load is equal to the 4:1 Rule of Thumb
- Weeks 1 and 2 required a workload equal to four 3 semester hour graduate school classes.



November 1, 2016

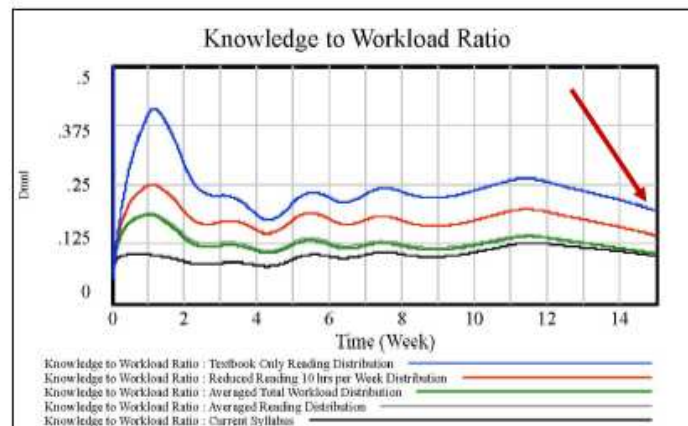
Modeling Analysis and Optimization of ENGR-532

9

9

Knowledge Gained vs Levels of Effort

- Compares the knowledge gained to the level of effort required to achieve that level of knowledge (efficiency)
- The most efficient scenario is to only assign textbook readings along with projects and assignments.



November 1, 2016

Modeling Analysis and Optimization of ENGR-532

10

10

Ask AI Assistant

Summarize this document



Recommendations

- Assign only textbook readings with minor additions for professional readings.
- Major reduction in required reading will promote a more efficient syllabus for the students to achieve better success.

Questions?



APPENDIX C: PRESENTATION TO ENGR-532, DYNAMICS OF COMPLEX ENGINEERING SYSTEMS, COURSE (11/8/2022)

In October of 2022, Dr. Kamran Eftekhari-Shahroudi, the professor for ENGR-532, Dynamics of Complex Engineering Systems (ENGR/SYSE-532), invited the author of this paper to present the current dissertation work to his class. The following presentation was given to the ENGR-532 System Dynamics course at Colorado State University on November 8th, 2022.

Aircraft Operations Optimization Using System Dynamics Modeling



TRENT "BEEF" KINGERY, PHD CANDIDATE

NASA RESEARCH PILOT/CHIEF, AVIATION SAFETY AT JOHNSON SPACE CENTER

1

Disclaimer

2

- ▶ The financial information contained in this presentation is fictitious but does show proper trends.
- ▶ NASA Public Relations has approved this presentation as long as actual financial data is not contained.
- ▶ The System Dynamics model is a work in progress and is continuously being refined to apply to actual Aircraft Operations.

AO Optimization Using SD

11/8/22

2

3

Overview

Who is "Beef" Kingery?

System Dynamics Applications

Complexity of Aircraft Operations

Tools in Application of SD to Aircraft Operations

NASA Aircraft Operations Model

Reference Modes

Results

Other Fun SD Models

AO Optimization Using SD 11/8/22

3

4

Trent "Beef" Kingery

- ▶ Retired Marine Corps Major (retired in 2014; 24 years; Mustang)
- ▶ Flown over 4,000 flight hours in high performance jet and corporate-type aircraft. 695 Combat Flight hours and 175 Combat Missions, 165 carrier arrested landings, awarded Nine Air Medals/Strike Flight
- ▶ BS Aerospace Engineering (1999), BS Electronic Systems Technologies (2015), MS Systems Engineering (2010), PhD Candidate Systems Engineering at CSU (2023)
- ▶ EA-6B Avionics Tech/Powerplants Mech, Instructor Pilot, Fighter Pilot, Acquisition Professional, Aerospace Engineer, and NASA Research Pilot
- ▶ Currently the Chief, Aviation Safety at NASA Johnson Space Center and Supervisory Research Pilot
- ▶ Dr. Shahroudi's SD course was the most challenging, but rewarding course taken at CSU.

AO Optimization Using SD 11/8/22

4

What is System Dynamics (SD)

5

- ▶ System Dynamics is a methodology and mathematical modeling technique to frame, understand, and discuss complex issues and problems. ¹
- ▶ System Dynamics is a computer-aided approach for strategy and policy design. It uses simulation modeling based on feedback systems theory and is an analytical approach that complements systems thinking. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems — literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality. ²

AO Optimization Using SD 11/8/22

5

Major Attributes of SD

6

- ▶ Time based (Dynamic)
- ▶ Computer/Software Driven (i.e. MATLAB® and VENSIM®)
- ▶ Stocks, Flows, Feedback Loops, Delays
- ▶ Linear and Nonlinear Effects
- ▶ Technical, Business, Decision Models
- ▶ Simplify Complex Analysis

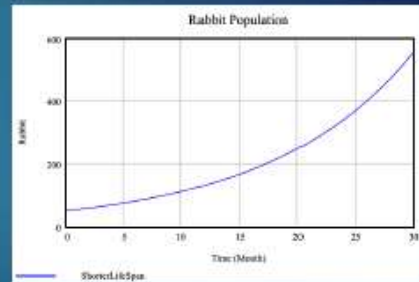
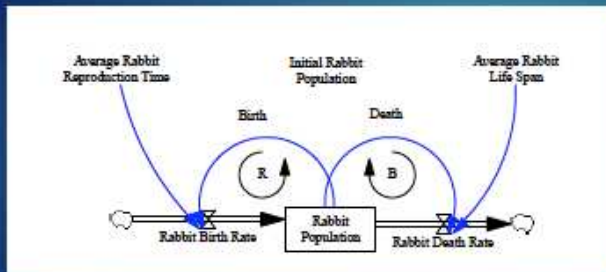
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6

Simple Example of System Dynamics

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► Population model (Birth/Death Rates)



AO Optimization Using SD 11/8/22

7

The Kamran SD Modeling Process

8

- Step 0: Determine Time Horizon, Time Step, Ref Modes, What, Why and Goal
- Step 1: Generate 14 +/- 4 Causal Loops that can dominate the response
- Step 2: Select the most influential 7 +/- 2 Causal Loop subset from Step 1.
- Step 3: Identify and Prioritize List of Candidate Stocks.
- Step 4: Kamran Rule of Stocks: Choose $\max(1, N_{\text{Loops}} - M) \leq N_{\text{Stocks}} \leq N_{\text{Loops}} - 1$ Stocks from prioritized list of candidates
- Step 5: Add Flows
- Step 6: Define at most NB Exogenous Variables
- Step 7: Rebuild Causal Loops around the Stocks, Flows and Exogenous Variables
- Step 8: Enter equations and define units
- Step 9: Check Model
- Step 10: Check Model Validity and Robustness

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8

Complexity of Aircraft Operations

9

- ▶ Aircraft Operations
 - ▶ Commercial Operations (Large Quantity)
 - ▶ Private Operations (Small Quantity)
 - ▶ Government Operations
- ▶ All can be based on a simple business model with sublevel modifications to accommodate the overall goal (e.g. revenue, budget execution, mission accomplishment)
- ▶ Very vulnerable to major events such as 9/11, COVID Pandemic, Fuel prices

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9

Problem Statement

10

Haphazard and uninformed decisions have been the downfall of many businesses [1]. Aviation-based organizations are no exception. Those aviation-based organizations are susceptible to failure due to the liability and high operating costs associated with flight operations [2]. In addition, it is difficult for decision makers at aviation-based organizations to assess the relative improvements of one decision versus another as there are many "knowns" and "known unknowns" that require intricate, constant analysis with consideration of projection effects into future years.

The use of a SD model can assist decisionmakers with "optimizing", through simulations, their operations to gain achievable profits and mission goals [3].

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10

Flight Operations at NASA JSC

11

- ▶ Instruct, Evaluate, and Test
- ▶ Fly Airborne Science Missions
- ▶ Support Launch and Landing Space Missions
- ▶ Corporate Type Flying (Covid)
- ▶ Various Ground Responsibilities



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Aircraft Types at AOD

12



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Space Flight Readiness Training

13



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Space Flight Readiness Training

14



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Astronaut Training/Launch Transport

15



SpaceX Crew 5



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Airborne Science Missions

16



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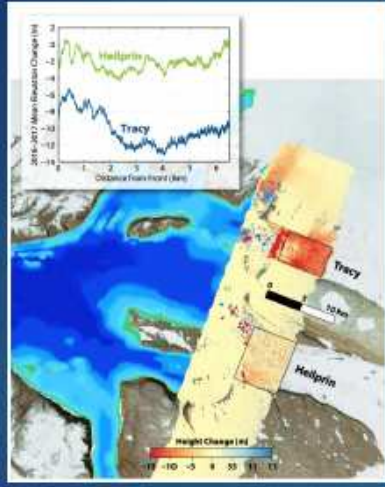
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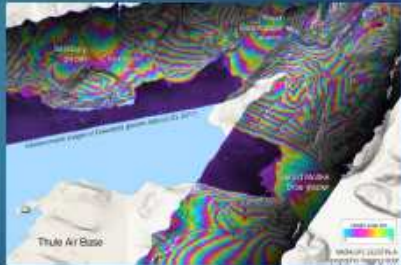
**Oceans Melting Greenland
OMG**



17



- High-resolution Digital Elevation Models over Greenland glaciers help:
 - Quantify ice melting and the role of ocean in melting rates
 - Model and predict patterns of sea level rise



<https://omg.jpl.nasa.gov/portal/>
 Ocean-ice interactions in Inglefield Gull: Early results from NASA's Oceans Melting Greenland mission
<https://doi.org/10.5670/oceanog.2018.211>

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San Andreas Fault Earthquake Studies



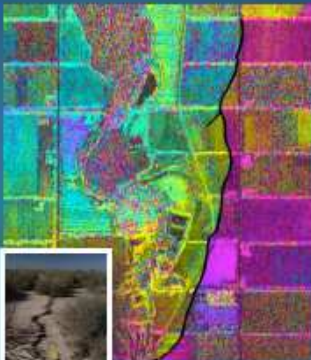
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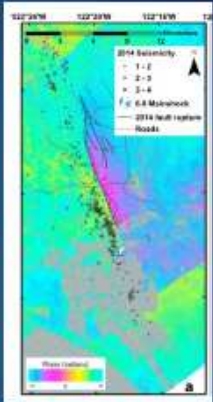
UAVSAR Swaths

Faults

- 2X year flights provide baseline conditions
- Post- earthquake images are compared with baseline and often reveal new fault lines



**Apr 4, 2010 M 7.2
Baja California Earthquake**



**Aug 24, 2014 M 6.0
Napa Earthquake**

AO Optimization Using SD

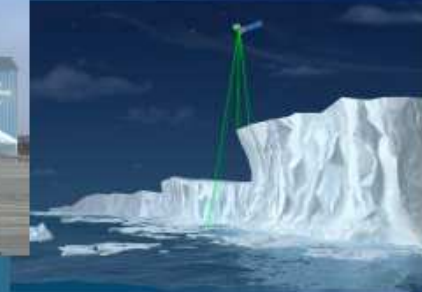
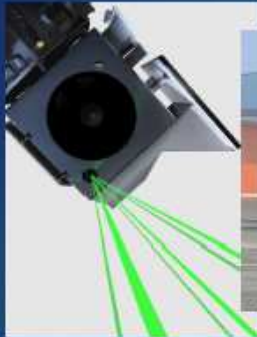
11/8/22

18



ICESAT-2 Campaign

19



- The Gulfstream V was flown using NADIR Port Laser to map Polar Ice as the ICESAT-2 Satellite flew overhead the Arctic. The Data gathered was used to calibrate and validate the satellite imagery.

<https://www.nasa.gov/content/ood/odata/about/icesat-2>

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ICESAT-2 Campaign

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<https://www.nasa.gov/content/ood/odata/about/icesat-2>

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ICESAT-2 Campaign

21



<https://www.nasa.gov/content/60000main/icesat-2>

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What would be the best metric(s)?

22

- ▶ How do you identify success or failure?
 - ▶ Type of organization
 - ▶ Government (Mission Based)
 - ▶ Commercial (Profit Based)
- ▶ What specific trends should we want to capture?
 - ▶ Asset Values
 - ▶ Expenditures
 - ▶ Revenues
- ▶ How do we break down the organization and different programs
 - ▶ Architecture

AO Optimization Using SD

11/8/22

22

NASA Aircraft Operations (AO) Model

23

- ▶ Modeled after government operations (baseline NASA)
- ▶ Budget/Mission driven (Space Flight Crew Operations; SFCO \$)
 - ▶ Pays for Space Flight Readiness Training (SFRT)
 - ▶ Primary funding source (every October at start of Fiscal Year)
- ▶ Reimbursable Revenue
 - ▶ Airborne Science Program (ASP) Funding
 - ▶ Department of Defense (DoD) Projects
 - ▶ Inter-Agency Support (Corporate-type flying)
- ▶ Low Quantity/High Variation Aircraft Types
 - ▶ Large Logistics Footprint (uncommon parts)
 - ▶ High Aircrew and Maintenance Training Costs

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NASA AO SD Model Characteristics

24

- ▶ VENSIM PLP
- ▶ Mostly Linear
- ▶ Multiple inputs that are active at different times make it difficult to manage
- ▶ Can implement feedback loops to replicate Supply & Demand effects
- ▶ Use of "Triggers" to activate variables at specific times
 - ▶ "Pulse" logic works well with "If/Then" Statements
 - ▶ Established data sets can be entered through "lookup" tables
- ▶ Use of a "Dashboard" with SyntheSim functionality is highly desirable.

AO Optimization Using SD

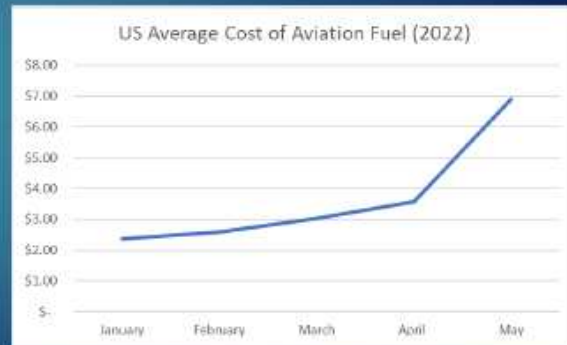
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Key AO Variables/Sensitivities

25

- ▶ Fuel Cost per Gallon
- ▶ Number of employees
- ▶ Average Wage of the employees
- ▶ COVID Protocols Active/Dormant
- ▶ Charge to Customer

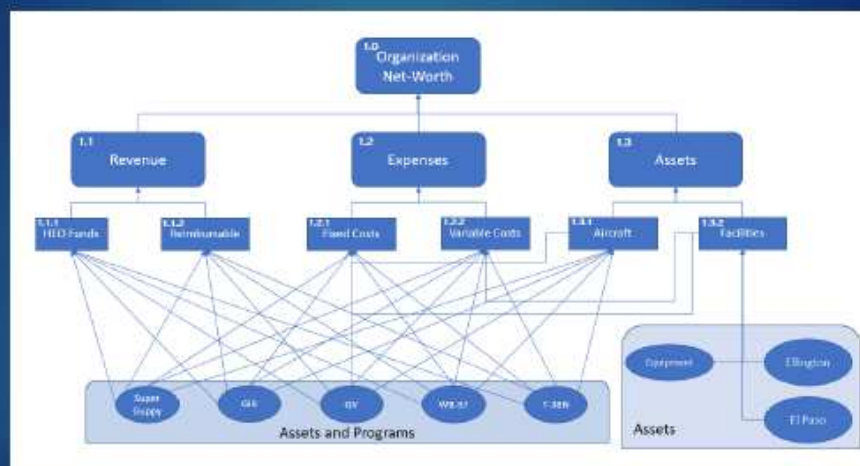


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NASA AO Architecture

26

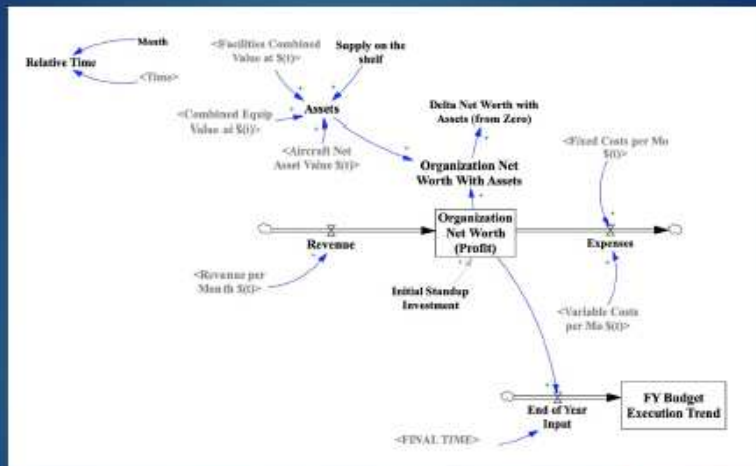


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Top Level AO Business Model

27



$$NW_{org}(t) = [V_A(t) + V_{Fac}(t)] + V_{SO}(t_0) + \int_{t_0}^t [R(t) - (C_F(t) + C_V(t))] dt$$

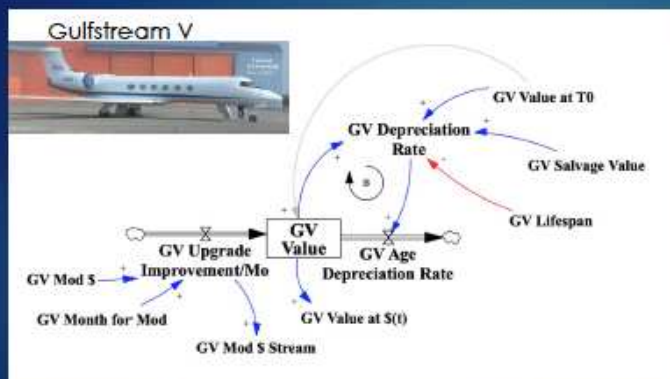
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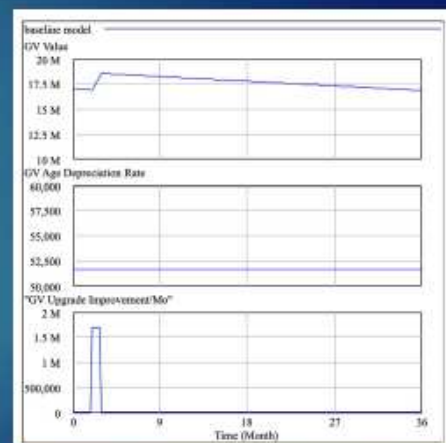
27

Asset Valuation

28



$$V_A(t) = V_A(t-1) + \int_{t=0}^t [V_A(t) - D_A(t)] dt$$



AO Optimization Using SD

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28

Fixed Cost (Expense)

31



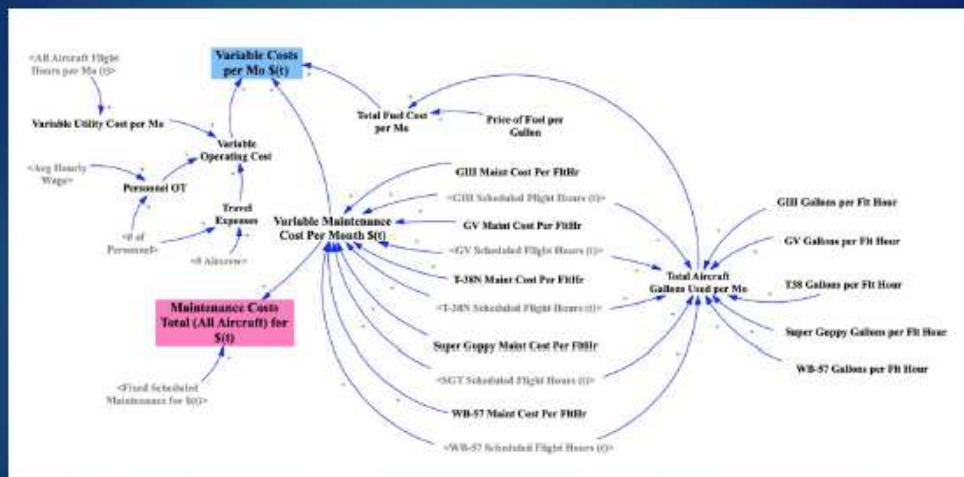
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Variable Cost (Expense)

32



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32

Reference Modes

33

- ▶ Validation and Verification of the Baseline Model
- ▶ 2019 (Normal Flight Operations)
- ▶ 2020-2021 (Pandemic Flight Operations)
- ▶ Delphi Counsel
 - ▶ Early on
 - ▶ Near the final SD Model Completion
- ▶ Metric Accessibility for Comparison

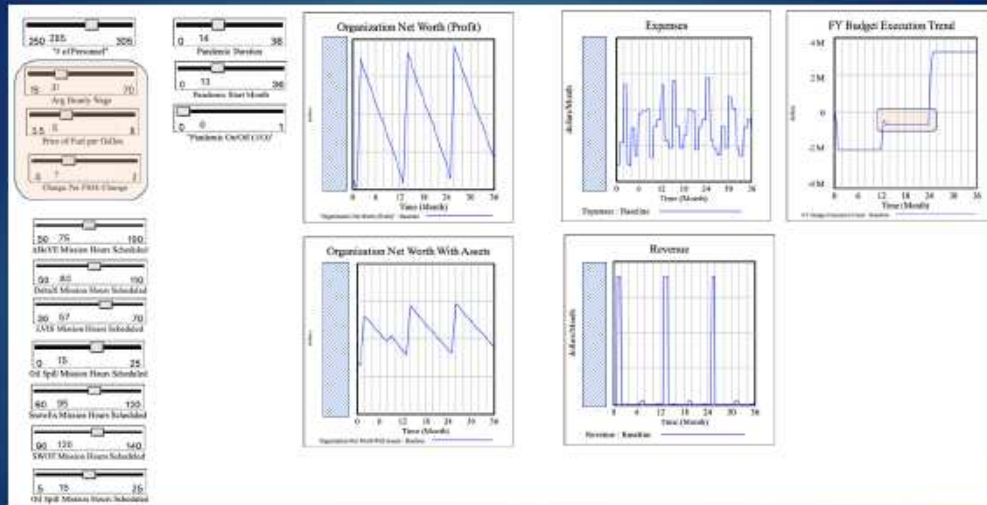


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2019 Normal Flight Operations

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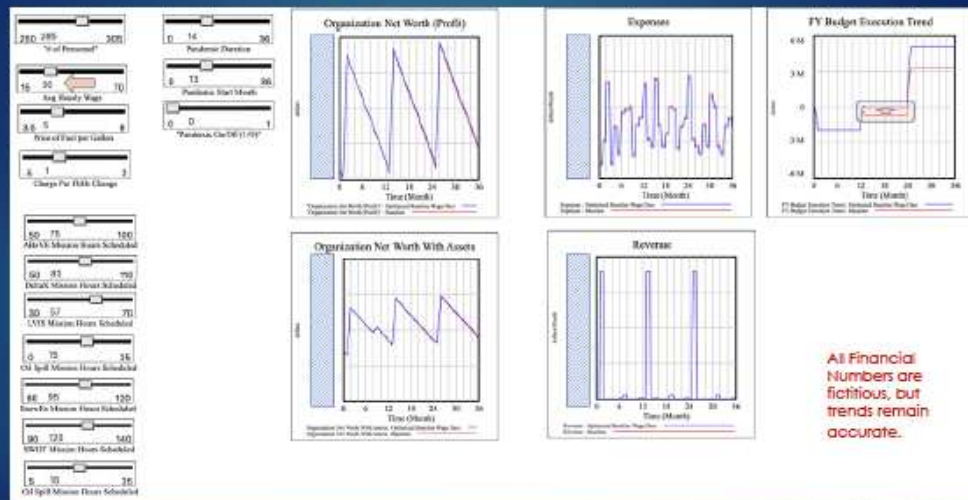


AO Optimization Using SD 11/8/22

34

2019 Normal Flight Operations

35



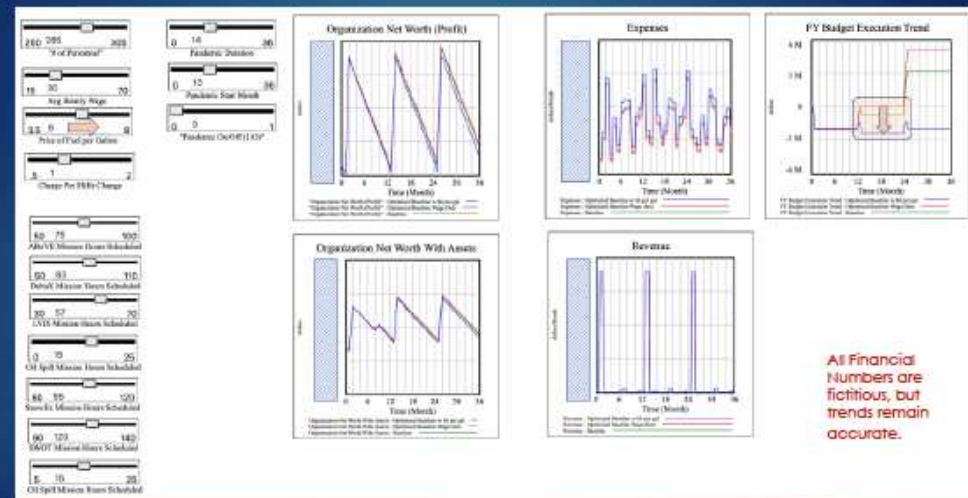
All Financial Numbers are fictitious, but trends remain accurate.

AO Optimization Using SD 11/8/22

35

2019 Normal Flight Operations

36



All Financial Numbers are fictitious, but trends remain accurate.

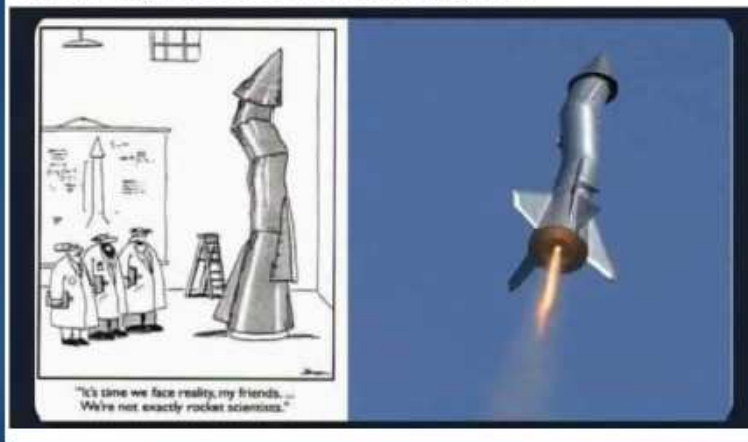
AO Optimization Using SD 11/8/22

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Questions on NASA AO SD Model?

39

Replica Gary Larson rocket that actually flew.



AO Optimization Using SD

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For Fun... Other SD Models "Student Knowledge Model"

40

- ▶ Learning Retention and Studying Efficiencies
- ▶ Key Metric: Hours of Knowledge Retained
- ▶ Used APA Case Studies on Learning Rates and Retention Rates
- ▶ Took a standard course syllabus and modeled it
- ▶ Optimized the course syllabus

AO Optimization Using SD

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For Fun... Other SD Models “Baseball Throw Model”

43

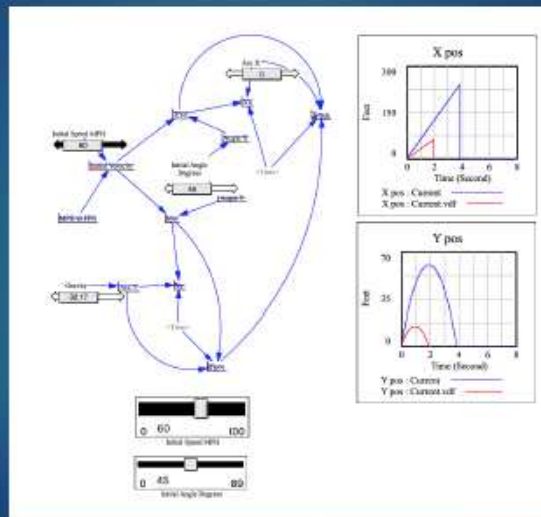
- ▶ Basic $F=MA$ (in the x and y axis)
- ▶ Linear (could use stocks for integration)
- ▶ Variables: Release Speed and Angle of Throw
- ▶ Assumption (drag was not accounted for)
- ▶ Fun with my kids (or at least I had fun)

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Baseball throw model

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Questions

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AO Optimization Using SD

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APPENDIX D: DELPHI COMMITTEES AND VALIDATION DETAILS

Delphi Committee #1

- Held on July 14, 2022
- Participants & Role:
 - T. Kingery (Presenter/Facilitator, Chief of Aviation Safety, JSC)
 - K. R. (Aviation Services Program Manager, AOD)
 - A. L. (Chief, Program Management Branch, AOD)
- Notes: Presented initial top-level model. Discussed how stocks, flows, and feedback loops function regarding process and funding models. Explained how “Value” was targeted as a key metric and if that would be ideal. All thought that would be the sufficient. Discussed architecture with A. L. (engineering background). Discussed key metrics that would be beneficial to “optimize”. It was determined wages, number of personnel, and flight hours flown per mission would be ideal to adjust.

Delphi Committee #2

- Held on January 18, 2024
- Participants & Role:
 - T. Kingery (Presenter/Facilitator, Chief of Aviation Safety, JSC)
 - J. G. (Aviation Service Program Manager, AOD)
 - R. B. (T-38N SFRT Program Manager, AOD)
 - D. E. (Deputy Operations Chief, AOD)
 - A. L. (Assistant Chief, AOD)
- Notes: Provided Updated Briefing on the system dynamics model with/without pandemic model engaged. Showed actual figures and results. Gave the PMs copies of the journal article drafted for the Journal of Air Transport Management that was later submitted to The System Dynamics Review. They all independently concurred that it was accurate

both in funding (revenue) and execution of expenses. All thought it was a great tool and could be useful if/when implemented.

Delphi Committee #3

- Held on April 28, 2026
- Participants & Role:
 - T. Kingery (Presenter/Facilitator, retired Chief of Aviation Safety, JSC)
 - B. H. (Programs and Infrastructure Branch Chief, AOD)
 - R. B. (T-38N SFRT Program Manager, AOD)
 - D. E. (Deputy Operations Chief, AOD)
 - A. L. (Assistant Chief, AOD)
- Notes: Provided Final Briefing on the system dynamics model with/without pandemic model engaged. Showed actual figures and results. All functionalities of the model were assessed to be accurate with the updated modifications. They liked the additional capabilities and stated that it is extremely beneficial for long term planning especially with the independent SFCO PPBE inputs. The committee members gave an update on aircraft and future training syllabi. R. B. stated that at the end of the Fiscal Year, monies can carry over into the following Fiscal Year if it is programmed or dedicated for procurement of parts or labor that is expected. This is a capability that he would like to see. I explained to him that this capability exists if the excess monies is used to purchase spare parts. Can make a separate “stock” for programmed funds in follow-on years in future versions. It is not necessary for this research and paper.

Presentation #1: ENGR-532 Presentation *Appendix C*, (Colorado State University)

- Held on November 8, 2022
- Participants
 - T. Kingery (Presenter, Chief of Aviation Safety, JSC)
 - Dr. K. E-S, Professor, Colorado State University

- 10 System Dynamics Students from ENGR-532 Fall Semester
- Notes: Presented the brief in *Appendix C*. Discussion was heavy on how to use triggers to initiate various states and changes in model functionality.

Presentation #2: AIAA North Carolina State University Chapter Presentation

- Held on October 15, 2025
- Participants
 - P. P., Chairman of the NC State University AIAA Chapter
 - 13 NC State University Students
- Notes: Provided an overview of NASA Aircraft Operations, astronaut flight training, airborne science missions, and system dynamics modeling.

Individual Meeting #1: Meeting with JSC Legal Counsel

- Held in January 2022
- Participants & Role:
 - T. Kingery (Presenter, Chief of Aviation Safety, JSC)
 - A. V.-X. (JSC Legal Counsel)
- Notes: Presented a detailed overview of the research and system dynamics model contained within this dissertation to determine if there were any legal issues. Counsel informed that the presentation had no legal restrictions and all data and metrics that was used to create the model can be obtained by anyone through the Freedom of Information Act (FOIA).

Individual Meeting #2: Personal Interview with the Director, Flight Operations Directorate, JSC

- Held in February 2022
- Participants & Role:

- T. Kingery (Presenter, Chief of Aviation Safety, JSC)
 - N. K. (Director, Flight Operations Directorate, JSC)
- Notes: Presented the background and “need” for a decision-making tool for PMs. He was open to the creation of the model and wanted an update when finished.

APPENDIX E: JSC NASAHFACS COMMITTEE CHARTER

JSC NASAHFACS CHARTER

Thorough, unbiased, and accurate human factors analysis to identify active and latent factors to mitigate and eliminate future adverse anomalies



COMMITTEE COMPOSITION

- ☐ Chairperson is the Chief, Aviation Safety Office or designate.
- ☐ JSC NASAHFACS Manager is the Chief Engineer, ASOFF.
- ☐ Anomaly investigator shall be present to answer any questions.
- ☐ All Anomaly NASAHFACS signatures must be NASAHFACS Certified or USC Viterbi HFACS course complete.
- ☐ Strive to have a diverse composition of specialties (e.g., Maintenance, Operations, Engineering, Safety).
- ☐ Minimum of 3 members for all Hazard, Close Call, Type-C-D Mishaps.
- ☐ Minimum of 6 members for all Type-A-B Mishaps and any High-Visibility Anomalies.
- ☐ Guest participants are encouraged to participate but only certified guests are allowed to sign the final analysis. Uncertified guest participants must complete the SATERN NASAHFACS OVERVIEW course (SMA-HQ-WBT-227) prior to attending a committee meeting.

CONDUCT OF ANALYSIS AND CLASSIFICATION

- ☐ Committee will perform their analysis when the investigation is 95% or more complete. This will allow the results to be incorporated into the Mishap Investigation Report.
- ☐ All participants are encouraged to provide their ideas without retribution/retaliation.
- ☐ Spider Chart and Nano-Code Definitions handout will be available to all participants.
- ☐ The Manager shall explain the process at the beginning of the committee for anyone who is a guest participant.
- ☐ Start with the investigator providing a summary of the investigation.
- ☐ Start the analysis at the ACTS level and work upward (e.g., ACTS, Preconditions, Supervisory, then Organization).
- ☐ Read out loud the Taxonomy Definitions as appropriate to ensure proper classification.
- ☐ Minimize "Double-Tapping" multiple nano-codes for the same contributing factor.
- ☐ Always finish up with determining if there are any "Green Lights."
- ☐ Only give "Green Lights" for actions/factors that went "Above and Beyond."
- ☐ Finish by assigning "Weights" to the assigned nano-codes.

POST ANALYSIS AND CLASSIFICATION

- ☐ Manager route and have participating committee members digitally sign final analysis report.
- ☐ Manager provide final analysis report to the Mishap Investigator to incorporate into his/her MIR.
- ☐ Manager enters data into NMIS for metric capture.

LIST OF ABBREVIATIONS

Abbreviation	Description
AEP	Agency Execution Plan
AOD	Aircraft Operations Division
AOG	Aircraft on Ground
AOP	Agency Operating Plan
AOP	Aircraft Operations Procedures
ARMD	Aeronautics Research Mission Directorate
ASO	Aviation Safety Officer
ASOFF	Aviation Safety Office
ASP	Airborne Science Program
CASO	Chief of Aviation Safety Office
CCP	Commercial Crew Program
CFR	Code of Federal Regulations
CONUS	Continental United States
COP	Congressional Operating Plan
CPA	Certified Public Accountant
CPFH	Cost per Flight Hour
CSA	Canadian Space Agency
DoD	Department of Defense
DoW	Department of War
EFD	Ellington Airport
ELP	El Paso International Airport

ESA	European Space Agency
ESDMD	Exploration Systems Development Mission Directorate
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FOD	Flight Operations Directorate
FOIA	Freedom of Information Act
FSO	Flight Science Officer
FTE	Full-Time Equivalent / Full-Time Employee
FY	Fiscal Year
GIII / G-III	Gulfstream III
GV / G-V	Gulfstream V
HEO	Human Exploration and Operations
HEOMD	Human Exploration and Operations Mission Directorate
HF	Human Factors
HFACS	Human Factors Analysis and Classification System
HQ	Headquarters
HR	Human Resources
HSI	Human Systems Integration
HSMD	Human Spaceflight Mission Directorate
HUD	Heads Up Display
IAOP	Intercenter Aircraft Operators Panel
IATA	International Air Transport Association
IP	Instructor Pilot
ISS	International Space Station

JAXA	Japan Aerospace Exploration Agency
JSC	Johnson Space Center
KPP	Key Performance Parameter
MIPR	Military Interdepartmental Purchase Request
MIT	Massachusetts Institute of Technology
NAMIS	NASA Aircraft Management Information System
NAOE	NASA Aircraft Operations Enterprise
NASA	National Aeronautics and Space Administration
NASAHFACS	NASA Human Factors Analysis and Classification System
NDI	Non-Destructive Inspection
NM	Nautical Mile
NMIS	NASA Mishap Information System
NOAA	National Oceanic and Atmospheric Administration
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NTSB	National Transportation Safety Board
O&S	Operations and Sustainment
OMB	Office of Management and Budget
OMG	Oceans Melting Greenland
ORD	Operational Requirements Document
OSMA	Office Of Safety and Mission Assurance
PDM	Programmed Depot Maintenance
POL	Petroleum, Oil, and Lubricants
PPBE	Planning, Programming, Budgeting, and Execution

PS	Personnel Support
PM	Program Manager
R&D	Research and Development
RCQ	Rear Cockpit Qualified Astronaut
RFI	Requests for Information
RFI	Ready for Installation
RFQ	Requests for Quotation
RM&A	Reliability, Maintainability, and Availability
SC&HF	Safety Culture and Human Factors
SD	System Dynamics
SE	System Engineering
SEO	Sensor Equipment Operator
SFCO	Space Flight Crew Operations
SFRT	Space Flight Readiness Training
SGT	Super Guppy Transport
SMD	Science Mission Directorate
SMS	Safety Management System
SOMD	Space Operations Mission Directorate
T/M/S	Type / Model / Series
USAF	United States Air Force
USCG	United States Coast Guard
USD	United States Dollar
USNTPS	United States Navy Test Pilot School