NASA/TM–20250009540

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December 2025

NASA STI Program Report Series

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Available from:

NASA STI Program / Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199
Fax: 757-864-6500

Abstract

This paper presents the Systems Engineering approach to the Streamlined Workflow for Innovative Flight Test (SWIFT) research activity, which aims to establish a cost-effective uncrewed aircraft research capability that facilitates rapid and flexible flight research across diverse platforms. The initiative focuses on developing a scalable, vehicle-agnostic architecture that enables standardized infrastructure for flight research, expediting the transition from concept to flight, particularly for high-risk technologies. Utilizing an existing NASA flight platform as a development testbed, the research activity emphasizes subsystem innovation while minimizing risks associated with platforms and infrastructure. Key components include advanced avionics, data acquisition systems, and modular designs that support a wide range of research applications. The research activity incorporates a tailored systems engineering approach to ensure compliance with airworthiness requirements, foster stakeholder engagement, and maintain traceability to NASA needs and research activity objectives. Ultimately, the SWIFT research activity aims to enhance midscale uncrewed aerial system capabilities, significantly contributing to NASA's aeronautics research objectives.

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Nomenclature

ARD	Aeronautics Research Director
ARMD	Aeronautics Research Mission Directorate
AFSRB	Airworthiness Flight Safety Review Board
CAS	Convergent Aeronautics Solutions
CE	Chief Engineer
CMP	Configuration Management Plan
COTS	Custom Off the Shelf
DM	Decision Memo
FRR	Flight Readiness Review
GMATT	Generic Modular Aircraft T-Tail
GNC	Guidance Navigation Control
GPS	Global Positioning System
ICD	Interface Control Document
IMU	Inertial Measurement Unit
MCR	Mission Concept Review
PI	Principal Investigator
PTERA	Prototype-Technology Evaluator and Research Aircraft
RAVEN	Research Aircraft for eVTOL Enabling Technologies
RF	Radio Frequency
SCREEMS	Small-scale Command & Control Remote End to End Mission Support System
SE	Systems Engineering
SIR	System Integration Review
SRD	Systems Requirements Document
SRR	Systems Requirement Review
SUSAN	Subsonic Single Aft Nacelle
SWIFT	Streamlined Workflow for Innovative Flight Test
TMP	Technical Management Plan
TP	Test Procedures
TPM	Technical Performanc Measures
TTBW	Transonic Truss Braced Wing
TTR	Tabletop Technical Review
UAS	uncrewed Aerial System

1 Introduction

The primary objective of the SWIFT research activity is to establish a cost-effective uncrewed aircraft research capability that emphasizes rapid and flexible flight research across multiple platforms, thus evaluating novel technologies with minimal risk. The initiative focuses on developing a system-level, scalable architecture that is vehicle-agnostic, allowing various platforms to leverage standardized infrastructure for flight research. By reducing cost by at least 30% and frequent flight opportunities, the research activity aims to expedite the transition from concept to flight, particularly for high-risk research.

This capability does not adhere to a one-size-fits-all approach but instead offers a standardized library of approaches tailored for mid-sized flight vehicles. It aspires to minimize risk from platforms, systems, and infrastructure, keeping risk only associated with the research experiment. The infrastructure allows for auxiliary activities, such as testing new features on existing vehicles, thereby maximizing research quality data collection.

The NASA Generic Modular Aircraft T-Tail (GMATT) platform development will demonstrate one use case and enable the development of midscale flight research subsystems with a wide range of applicability within the programmatic 2 year deadline. GMATT serves as a tangible asset for testing and integrating all critical components while its availability ensures near-term research applicability while minimizing cost. Furthermore, the research activity involves human and hardware infrastructure development, necessitating the building of a multidisciplinary flight test team and incorporation of advanced technologies like the modular and scalable COTS computer and high-performance data acquisition system.

Through a deliberate build-up approach, the research activity emphasizes rapid experimentation, process development, and risk reduction, paving the way for the development of other uncrewed flight research vehicles. Ultimately, these development processes will enhance flight testing capabilities that support related research activities like Subsonic Signle Aft Nacelle (SUSAN), Research Aircraft for eVTOL Enabling Technologies (RAVEN), and Transonic Truss Braced Wing (TTBW), thus contributing to a flexible, efficient, and impactful aerospace research environment.

2 Technical Summary

Midscale uncrewed aerial systems are slated between 55 and 330 lbs. and occupy a trade space with high research upside but minimal COTS options. The research capability of this aircraft class is bolstered by the weight and volume capability to accommodate medium sized data acquisition, research computing, control computing, and scientific payloads. But, due to limited COTS options, these aircraft tend to be custom built leading to higher costs, longer lead times, and more difficult airworthiness certification than smaller off-the-shelf platforms. To reduce these barriers to flight for this class of aircraft, SWIFT aims to develop widely applicable and capable flight systems for these vehicles. The development of these systems is not limited to the technical effort but extends to the certification process, ideally establishing trust in these systems and expediting future use cases. To accomplish the development of such systems, a midscale flight platform is needed. The GMATT vehicle is well suited for this work as it is an existing airframe built several years before the SWIFT research activity, within the relevant size and performance range, and readily available for modification and testing.

Figure 1: GMATT Aircraft Isometric Views [1]

Prior to the SWIFT activity, the development of the uncrewed Prototype-Technology Evaluator and Research Aircraft (PTERA), and sister aircraft Generic Modular Aircraft T-Tail (GMATT), was completed by Area-I, Incorporated in collaboration with NASA and Boeing [1]. Designed as a versatile, cost-effective flight research testbed, these aircraft bridge the gap between wind-tunnel and manned flight testing by offering low-risk flight evaluation for high-risk technologies. The aircraft features a modular design allowing for significant reconfigurability, including a 16%-scale CRJ-700 configuration dubbed PTERA-RJM, tailored for the NASA Aviation Safety Program. Enhanced during its Phase I program with an unprecedented modular configuration, the platform can support experiments in various fields, such as vehicle health monitoring, structural analysis, and atmospheric hazard sensing. The aircraft include a large, easily transportable airframe, modular wing and fuselage designs, an integrated ballast system, and extensive payload capacity, all while maintaining low costs. GMATT's reconfigurability allows for rapid prototyping and testing across a wide range of experiments, significantly reducing development costs and timeframes while identifying issues early on.

Property	Full-scale	Model	Unit
Aircraft Scale	100	15.8	%
Wingspan	915	147	inches
Total Length	1280	204	inches
Fuselage Length	1171	185	inches
Fuselage Height	106	17.28	inches
Maximum Takeoff Weight	75,250	287	pounds
Airspeed	270	107	knots
Takeoff Thrust (per engine)	12,670	50	pounds

Table 2: GMATT Vehicle Performance Specifications [1]

The flight systems block diagram is shown in Figure 2 where onboard electronics and their interfaces are indicated. This figure shows an integrated system with minimal categorization, for organization, the GMATT vehicle flight system is broken down into the following subsystems:

- **Airframe & Propulsion**: Includes the structural components of the UAS such as the fuselage, wings, control surfaces, landing gear, and any other structural elements that define the vehicle's shape and provide structural integrity. Also includes the engine(s) or motor(s), propeller(s), fuel system (for combustion engines), and any associated hardware required to generate thrust for the UAS.
- **Avionics**: Encompasses the electronic systems used for navigation, sensing, and control of the UAS. This includes GPS systems, inertial measurement units (IMUs), flight computers, sensors, and any other electronic devices used for mission planning and execution.
- **Data Acquisition System**: Responsible for collecting and recording data during the flight. This may include environmental sensors (temperature, humidity), flight data sensors (altitude, speed, flow angles), payload sensors, and any other specialized sensors related to the UAS's mission.
- **Power**: Consists of batteries or other energy storage devices, power distribution units, voltage regulators, and any necessary components to supply power to all onboard systems, including propulsion if electric.
- **Flight Control Computing**: Includes the onboard computers and software responsible for processing inputs from sensors, executing control algorithms, and managing flight dynamics. This subsystem ensures that the UAS maintains stable flight and follows the desired trajectory.
- **Guidance, Navigation, and Control**: Uses onboard sensors, positioning systems and control software to estimate the vehicle's state, plan its trajectory, and maintain stability.
- **Flight Termination System**: Designed to safely terminate the flight in case of malfunction or deviation from the predetermined operation. This could include mechanisms to return to launch the UAS or disable its propulsion system.
- **Communications & RF**: This subsystem includes the communication components used for transmitting and receiving data between the UAS and ground control, as well as any RF systems for communication with other vehicles or control stations.
- **Ground Control Station**: Consists of the hardware and software used by ground operators to control the UAS and monitor its status. This may include computers, screens, control sticks, data links, and user interfaces for mission management and real-time data analysis. The intended system to be used is existing and operated at NASA Armstrong Flight Research Center (AFRC).

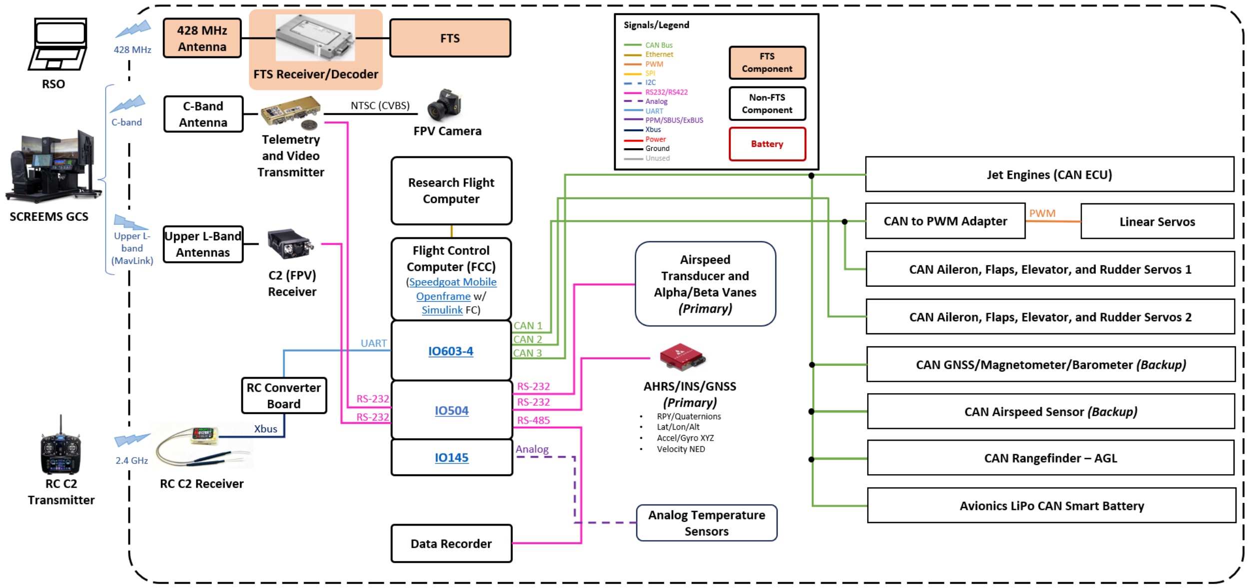

Figure 2: SWIFT GMATT Preliminary Flight Systems Block Diagram [2]

The boundary of technical effort for the NASA SWIFT research activity, focused on developing a scalable architecture for midscale UAS, is defined by a strategic approach centered around utilizing the GMATT vehicle as a development platform. This research activity is distinct in its goal, as the primary deliverable is not the GMATT vehicle itself, but rather the innovative subsystems engineered to be both highly capable and highly adaptable. This distinction delineates the scope of the technical team's effort — their focus is on subsystem innovation rather than the vehicle. However, due to being stored for several years after assembled but never flown, development of the vehicle to a functional level is necessary to adequately demonstrate the key subsystems. Within the boundary of technical effort, the technical team has control over the design, development, and testing of these advanced subsystems. This involves establishing a comprehensive understanding of the architecture needed to ensure scalability and performance across various operational environments. The research activity emphasizes developing technologies that can be standardized for widespread application, thus underlining adaptability as a core characteristic.

Crucially, the only significant interface for the GMATT vehicle and respective architecture involves integrating with Small-scale Command & Control Remote End to End Mission Support System (SCREEMS), the existing ground control station system at NASA AFRC. While SCREEMS itself is not under the direct control of the SWIFT team, a seamless interface with this system is essential for remote mission operations. This interface represents the research activity's main point of influence beyond its defined boundaries, requiring careful consideration to ensure compatibility, functionality, and performance integrity. In summary, the SWIFT research activity's boundary of technical effort is focused on subsystem development within the GMATT platform, prioritizing adaptability, modularity, and adaptability while aligning with existing ground control systems like SCREEMS. By delineating these boundaries, the team can effectively manage resources, mitigate risks, and deliver innovative solutions that fulfill the research activity's ambitious objectives in advancing midscale UAS research through a rapid concept-to-flight capability.

3 Organization and Responsibilities

3.1 Decision Authority

- Technical Authority: AFRC ARD delegated to AFRC CE
- Project Authority: PI-CAS
- Airworthiness Authority: AFRC Airworthiness Flight Safety Review Board (AFSRB)

3.2 Leadership Structure

1. Principal Investigator: Overall responsibility for research activity execution, budget, personnel management, compliance with regulations, and stakeholder management.
2. Discipline Lead: Responsible for the technical development and of the respective vehicle subsystem(s).

3.3 Engineering Disciplines

- **Flight Systems**: Develops the core electronic components and technologies necessary for the functioning and control of small/mid-scale airborne vehicles, focusing on achieving desired performance and research-capable systems during all phases of flight.
- **Guidance, Navigation, and Control (GNC)**: Focuses on the algorithms and systems required to direct an aircraft's path and maintain vehicle stabiility, ensuring accuracy and efficiency in reaching desired destinations and maintaining intended flight conditions.
- **Flight Processes**: Investigates and refines the operational procedures and workflows essential for efficient flight operations, enhancing safety and reliability through systematic analysis and improvement.
- **Airframe Development**: Addresses the design and manufacturing of the structural and propulsive framework of aircraft, ensuring that it meets aerodynamic requirements and withstands operational stress and environmental conditions.
- **Flight Operations**: Coordinates efforts with range safety, RC safety pilot, and GCS operator and personnel, ensuring execution of flight missions and adherence to safety protocols.
- **Systems Engineering**: Provides oversight of the systems engineering process, coordination of technical reviews, and ensuring that system development aligns with stakeholders' needs and requirements, ensuring cohesive research activity execution.

4 Stakeholder Engagement

Involving stakeholders early in the system design process is a key aspect of systems engineering as it is crucial to aligning the system needs, goals, objectives, and requirements with all associated parties. The stakeholders identified for the SWIFT research activity included groups in industry, federal and state government entities, and within NASA. These stakeholders are mapped in Figure 3.

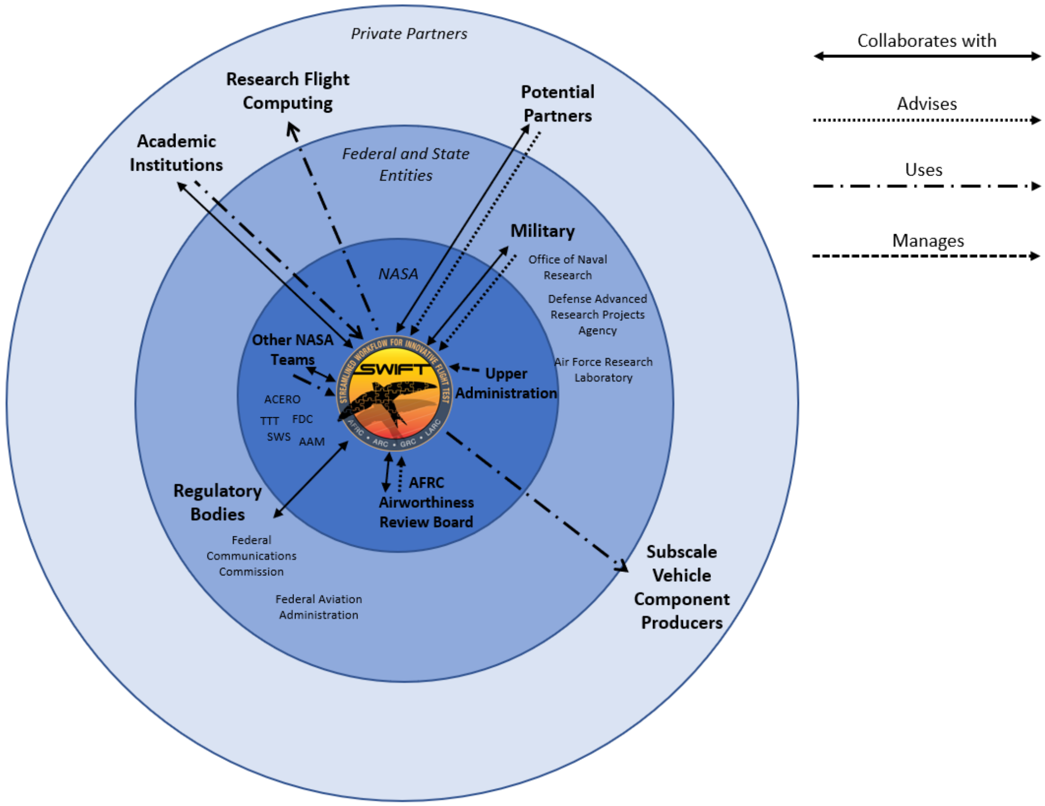

Figure 3: SWIFT Stakeholder Map

To align SWIFT's capabilities with the needs of end-user stakeholders, the team conducted a survey solely among NASA aeronautics research groups. This subgroup of stakeholders was chosen as they have the highest probability of being the end user and dictating vehicle requirements. The survey was designed to gather insights on system-level decisions for SWIFT as well as individual flight vehicle design, soliciting feedback on vehicle characteristics, programmatic desires, and technical capabilities. It addressed areas such as payload and speed preferences, UAS type suitability, budget considerations, and risk tolerance while also gauging the demand for enduring versus one-off test capabilities. A selection of key responses is shown in Figure 4 with the full survey description in Appendix A.

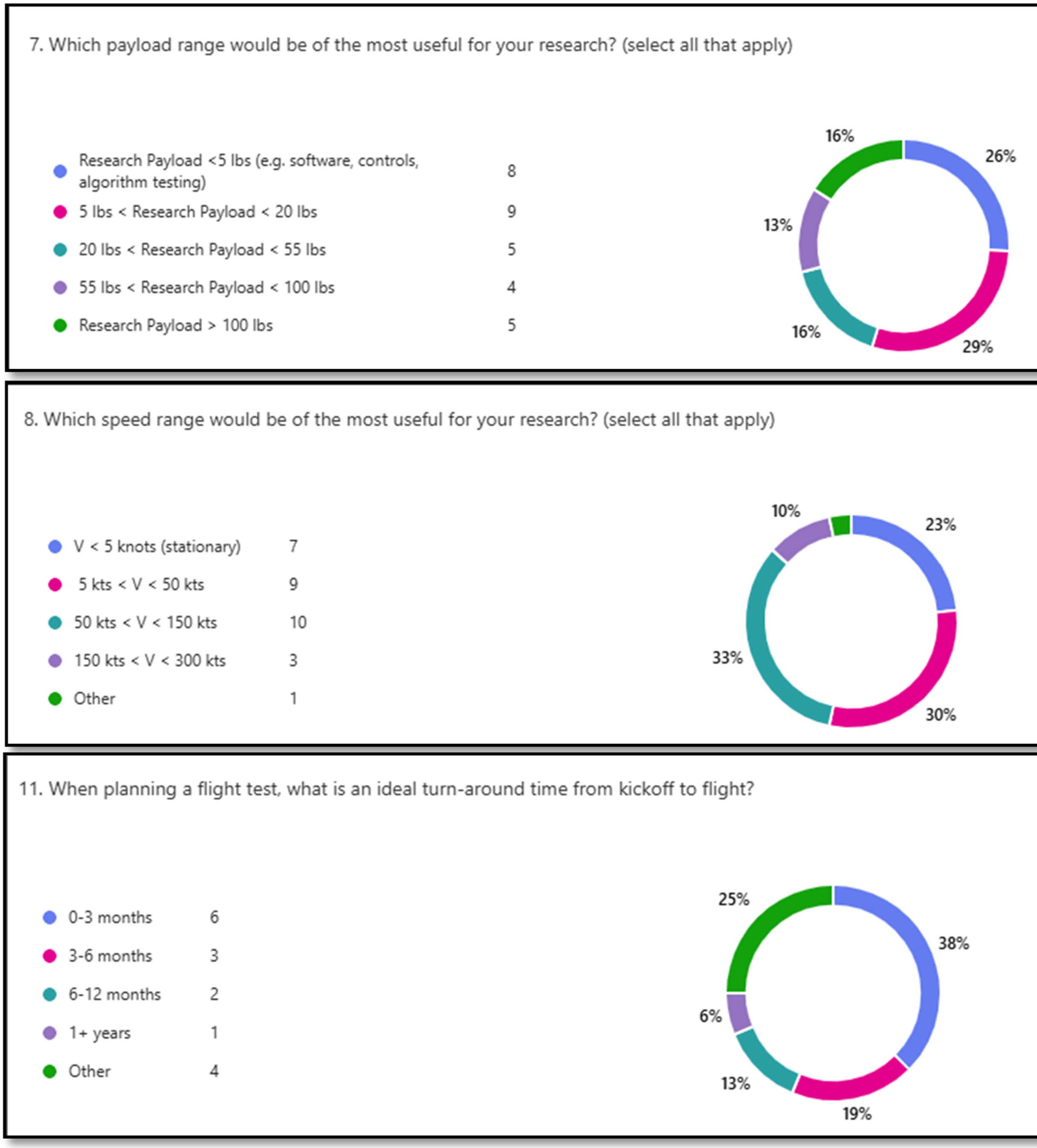

Figure 4: Key NASA SWIFT Researcher Survey Results

Respondents emphasized the necessity for cooperative approaches with ongoing development projects for larger aircraft, pertinent to Advanced Air Mobility (AAM). A key response of a desire to reduce concept to flight times from the typical 1-2 years was the highest impact theme of the survey, and drove multiple SWIFT objectives. While SWIFT is seen as a critical advancement in flight research, addressing every survey request is impractical. However, a design targeting 80% of these requests would balance feasibility and desirability, schedule speed and high-quality data acquisition over vehicle performance. Overall, the positive feedback from the survey underscores

SWIFT's potential to fill a significant gap in aeronautics research.

5 Needs, Goals, Objectives, and System Requirements

The value and intent of Needs, Goals, and Objectives (NGOs) is described best by the NASA Systems Engineering Handbook [3] as:

> "In order to define the goals and objectives, it is necessary to elicit the needs, wants, desires, capabilities, external interfaces, assumptions, and constraints from the stakeholders. Arriving at an agreed-to set of goals and objectives can be a long and arduous task. Proactive iteration with the stakeholders throughout the systems engineering process is the way that all parties can come to a true understanding of what should be done and what it takes to do the job. It is important to know who the primary stakeholders are and who has the decision authority to help resolve conflicts.
>
> Needs, Goals, and Objectives (NGOs) provide a mechanism to ensure that everyone (implementer, customer, and other stakeholders) is in agreement at the beginning of a project in terms of defining the problem that needs to be solved and its scope. NGOs are not contractual requirements or designs.
>
> Needs are defined in the answer to the question "What problem are we trying to solve?" Goals address what must be done to meet the needs; i.e., what the customer wants the system to do. Objectives expand on the goals and provide a means to document specific expectations. (Rationale should be provided where needed to explain why the need, goal, or objective exists, any assumptions made, and any other information useful in understanding or managing the NGO.)"

NGOs were developed early in the systems engineering life-cycle for the SWIFT research activity and are shown in Figure 5. In summary, SWIFT is intending to improve idea to flight times for NASA aeronautics research projects in a lasting manner and change NASA's approach to scale UAS testing. The efforts to accomplish these intentions are tailoring the necessary airworthiness process, create a persisting capability with user and institutional funding, utilize existing capabilities and expertise wherever available, develop a common flight architecture system, apply that architecture system to multiple UAS scales (micro, small, mid, etc.), partner with a high-risk high-impact research activity, and capture lessons learned.

While the NGOs describe the holistic intent and plan for the SWIFT research activity, the GMATT vehicle system is only expected to accomplish a portion of the research activity's goals and objectives (Objectives 3, 5, and 6 in Figure 5) and serve as a platform to then accomplish the remaining objectives. The GMATT system level requirements are listed below and, due to being early in the lifecycle of this activity, there are not yet detailed rationale statements for these requirements. This list outlines a system created to be a flight platform with adequate performance capabilities coupled with data acquisition, control, and research capabilities. Such a system allows the team to gain experience with the airworthiness process, demonstrate common architecture designs, and attract funded research activities. The performance of this system is not traced specifically to stakeholder needs as the design is primarily predetermined by the existing GMATT vehicle yet tailored to support subsequent vehicles. However, the GMATT vehicle does trace to the currently unfilled gap in NASA mid-scale UAS testing platforms and architectures.

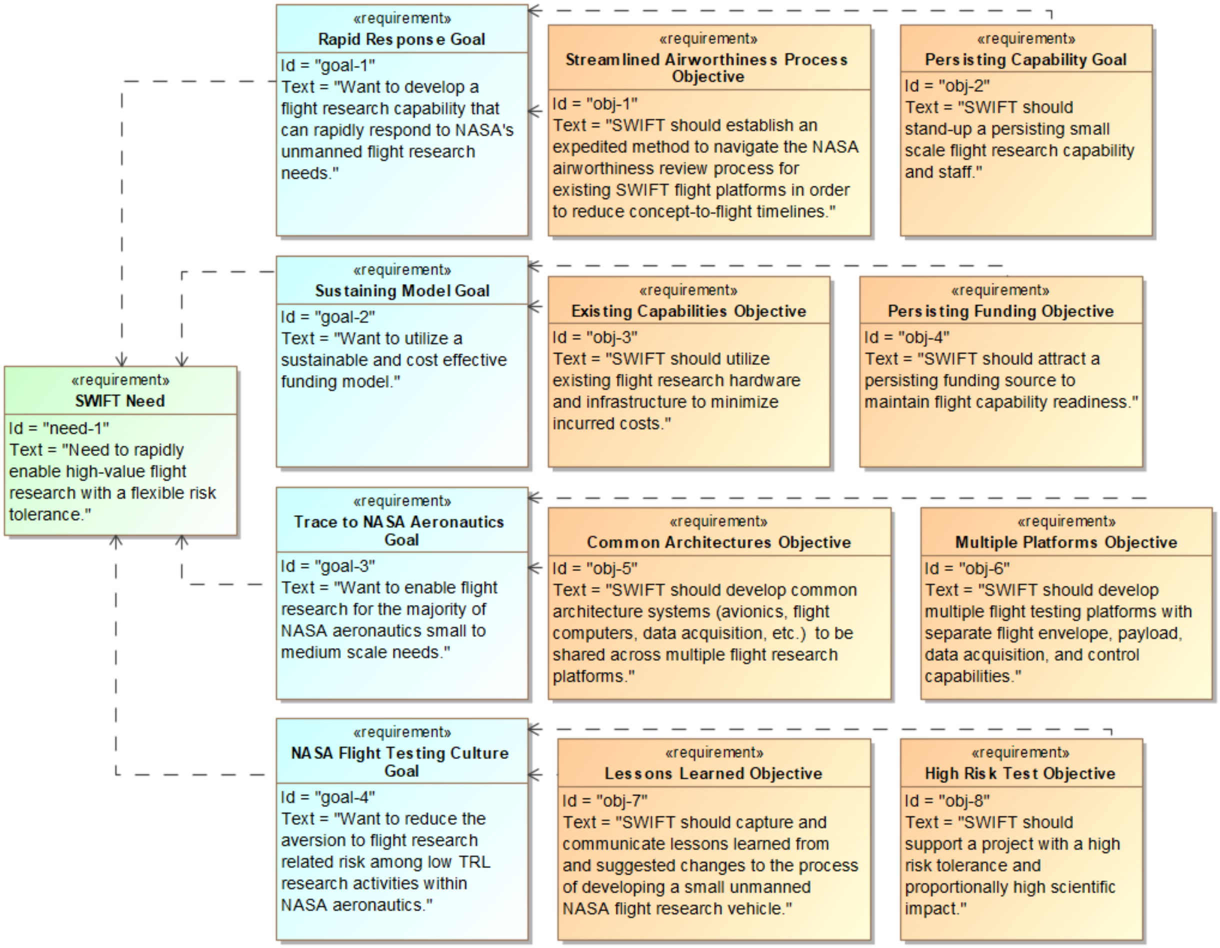

Figure 5: SWIFT Needs, Goals, and Objectives

1. GMATT shall fully document all custom designs, rationales, and suggestions for future UAS designers.
2. GMATT shall achieve airworthiness approval in order to gain approval to fly, experience with the system, and rapport with the airworthiness review boards.
3. GMATT shall have a time source accurate to 1e-6 seconds.
4. GMATT shall accept flight control commands from either a ground pilot or the autopilot system.
5. GMATT airframe shall provide outer mold line geometry and all mechanical structure necessary for flight and ground operations.
6. GMATT shall have a system to measure and adjust vehicle states with capabilities necessary for standard flight research.
7. GMATT shall have a system suitable for use on multiple UAS platforms capable of recording all avionics data, avionics parameters, and instrumentation data.
8. GMATT shall contain a power system to power all onboard electronic components for the duration of the flight.
9. GMATT shall have a flight control computing system suitable for use on stable and unstable midscale UAS platforms to execute flight control commands.
10. GMATT shall develop flight software and GNC algorithms that enable stable flight and

mission capability across all intended aircraft configurations and flight profiles.

11. GMATT shall have a system that terminates flight in a controlled fashion.
12. GMATT shall be able to send and receive communications to and from the ground control station and pilot.
13. The SCREEMS Ground Control Station (GCS) shall be used to control the vehicle from the ground and provide real time monitoring of flight parameters.
14. GMATT shall be capable of self powered flight up to 5000 ft MSL.
15. GMATT shall be capable of nominal operation in all environments between AFRC ramp conditions and the aircraft maximum altitude.
16. GMATT shall be capable of storing sufficient fuel to perform a 30 minute research flight in addition to ground taxi time.
17. GMATT shall achieve self-propelled level flight at least 140% of the maximum stall speed.
18. GMATT shall have a thrust to weight ratio of at least 40
19. All GMATT systems shall start into a known safe state.

6 Definition of Risk and Risk Management

Risk is defined as the possibility of failing to meet an objective. The risks for the SWIFT activity are split amongst two groups, the SWIFT activity itself, and the research users of the SWIFT flight test vehicles. Risk for the SWIFT activity is defined as the potential for SWIFT to not meet the NGO's mentioned in the previous section within the allotted 2 year schedule. These NGO's blended both programmatic speed, long term flight research costs, and meeting the technical and cultural needs of NASA Aeronautics. The risk associated with the research users of vehicles provided by the SWIFT activity is defined as the potential of a flight test campaign to not meet their requirements or exceed a typical user's available schedule and cost threshholds. Risks between these two groups are largely shared but the SWIFT activity views risks across multiple flight test campaigns while the end research users view risk only associated to their specific flight test campaign. Risk postures ("high" vs "low") mentioned throughout this paper refers to the probability of the loss of the flight research vehicle and payload without the potential for human injury. This is a consideration at the center of the SWIFT activity caused by the desire to reduce the UAS flight research timeline and costs.

Programmatic risks that could lead to schedule and budget overruns often opposed the technical risks that could cause the loss of the vehicle or diminished performance metrics. Budget was not regularly a limiting factor for the SWIFT activity so risk management decisions amongst the team were often balancing scheduling risks with technical risks. The SWIFT activity did not implement any defined risk management tools or processes but relied on intentional debates with the SWIFT team and overarching CAS project along with stakeholder input to establish acceptable risk postures for various potential shortfalls. An area where the SWIFT activity had a very low risk tolerance was range safety or the risk associated with crashing a vehicle near people, equipment, and buildings. This risk is managed rigorously through the AFRC airworthiness process and the technical reviews, specifically the Flight Readiness Review or "Tech Brief".

7 Technical Review Description

The research activity, characterized by its relatively small scale and constrained schedule, necessitates tailoring due to its unique features and challenges. Unlike conventional research activities where all subsystems are developed concurrently, this research activity faces high variance in existing subsystem development levels as the airframe is already complete while the flight software stack, flight computer, and avionics require full development. This disparity requires careful management to synchronize development timelines efficiently. Although typically such small research activities might opt for significant relief from standard systems engineering processes, this research activity involves the critical aspect of being a flight research activity with mandatory airworthiness requirements. Consequently, the airworthiness process, along with all necessary reviews, must be adhered to rigorously. Tailoring becomes essential to balance these constraints, facilitating a streamlined but compliant approach that accommodates the research activity's time limitations while ensuring safety and performance standards are met.

Tailoring is a process recognized by NASA policy to achieve mission success efficiently and economically by accommodating the unique aspects of each program or project. Tailoring involves waiving or modifying (customization) specific system engineering (SE) requirements. Both tailoring and customization are essential for establishing appropriate SE requirements, especially for small projects with focused, advanced technology objectives and limited resources. The goal is to maximize project success by fitting SE requirements to the project's needs, reducing unnecessary overhead, and maintaining a clear understanding of acceptable risks among stakeholders. Effective tailoring involves applying lessons learned and best practices, supported by systematic approaches and experienced guidance.

By significantly reducing the review cycle, the research activity aims to retain the essential value of systems engineering without the excessive rigor typical for larger activities. This approach includes maintaining essential programmatic input while effectively gathering technical feedback on designs, minimizing both mission and technical risk. A flexible schedule for subsystem design reviews is paramount due to the variable development levels of different research activity components, such as the completed airframe and the ongoing development of the flight software stack and avionics. To address these needs, the SWIFT research activity's tailored review cycle begins with a Mission Concept Review to ensure alignment with overarching program goals, combined with a System Requirements Review to detail key system functions, architectures, and interfaces. To capture technical input and manage scheduling discrepancies, tabletop technical reviews for subsystems will be held asynchronously. These provide independent critiques and accommodate misalignment in subsystem development schedules. A Systems Integration Review focuses on combining subsystems to mitigate integration risks. Finally, a Flight Readiness Review or "tech brief" is to be held to affirm operational procedures and readiness for mission success.

This tailored approach blends a reduction of procedural rigor while maintaining independent input, thereby minimizing technical risks while allowing flexibility and responsiveness in execution. By adapting the review process in this manner, the SWIFT research activity can achieve its objectives within its constrained time frame while ensuring technical robustness and mission readiness. Additional definitions of entrance and exit criteria for each review can be found in Appendix B. In alignment with the technical authority structure descrbed in Section 3, the AFRC CE office will oversee these reviews.

- **Systems Requirement Review (SRR)/Mission Concept Review (MCR)** – The objective of the System Requirements Review and Mission Concept Review is to assess and validate the readiness of a mission/research activity to advance to the next phase of its lifecycle. This involves a thorough examination of key elements such as program requirements, stakeholder expectations, technical feasibility of the concept, mission success criteria, and primary program risks. The review ensures that all stakeholders are aligned on the mission's feasibility, objectives, and the defined approach for verifying compliance with program requirements. It also evaluates preliminary assessments of risks, costs, schedules, and technical plans to ensure they are credible and align with strategic goals. The SRR/MCR process includes agreeing on an agenda, success criteria, assessing feasibility and alignment of alternative concepts, and ensuring that risk mitigation and external system interfaces are mature and effective.

- **Tabletop Technical Reviews (TTR)** - The objective of the Tabletop Technical Reviews are to evaluate and affirm the readiness of a subsystem to progress into the next phase by ensuring that preliminary designs meet technical requirements and performance measures. It includes an informal examination by attendees and team members of designs, subsystem specifications, risk assessments, analysis results, and interfaces. Key focus areas include verifying that top-level and verifiable requirements are finalized, ensuring that the design is expected to meet requirements with acceptable risk and margins, and confirming that system interfaces and associated risks are adequately identified and managed. It also assesses whether new technologies are ready, safety and mission assurance requirements are addressed, and technical and programmatic margins are sufficient. The review ensures the operational concept is sound, trade studies for alternative solutions are nearing completion, and plans are in place for resolving any open items.
- **System Integration Review (SIR)** - The objective of this System Integration Review is to ensure that a project is prepared to move forward to system level runway testing, having successfully completed previous life-cycle reviews and resolved or planned for closure of outstanding action items. The focus is on confirming that initial verification and validation (V&V) results are ready, and that mechanical and electrical interfaces for required hardware adhere to interface control documentation. The review assesses the readiness of functional, unit-level, subsystem, and qualification testing to support system testing. It also evaluates updated design solutions, interface definitions, and V&V plans.
- **Flight Readiness Review (FRR)/Tech Brief** - The objective of the Flight Readiness Review or "Tech Brief" is to confirm that a combined system is fully prepared for flight or mission operations, ensuring that all configurations, interfaces, and support elements function as required and meet go/no-go criteria for flight. This review evaluates the readiness of final certifications for flight and verification and validation results, alongside updated as-built hardware, software documentation, and operational procedures. It ensures that all necessary radio frequency spectrum authorizations are in place and examines an updated list of single point failures and their effects. The review also confirms that the flight vehicle or system is safe for operation, the software elements are prepared for flight, and that interfaces are functional. It ensures all open action items are resolved and all safety and mission risks are addressed with residual risk considered acceptable. The review also verifies the readiness of supporting organizations.
  - **Mini-tech** - Similar to the FRR or Tech Brief, a "Mini-tech" will be employed prior to subsequent test campaigns that only involve minor modifications to the agreed upon operations and technical design of the system. The content of this review will mirror that of the larger Tech brief but minimize or summarize unchanged aspects of the system. Ideally, this review will reduce redundancy in the review process while maintaining proper risk management of novel technology and operations.

8 Technical Documentation

Consistent documentation is essential in engineering research activities for effective communication among stakeholders. It serves as a foundation for capturing critical information and reducing the risks of miscommunication and errors. A standardized documentation facilitates informed decision-making throughout the research activity life cycle. To meet the rapid nature of the SWIFT process, a "document-as-you-go" approach is adopted with an emphasis on automated documentation tools built into engineering tools. The following section outlines the necessary documents for this research activity and highlights their intended value.

- **Technical Management Plan (TMP)** - The TMP is a crucial document that outlines the technical and engineering activities for a research activity, serving as the main guide for technical integration and execution. It provides detailed information on technical processes, organizational strategies, and resource allocation necessary to achieve objectives. The TMP is essential for ensuring consistent technical integration, interfaces, and management across stakeholders, including the technical team, program managers, and customers. As a living document, the TMP is continuously updated throughout the project life cycle to reflect changes and ensure alignment with research activity goals and requirements.
- **System Requirements Document (SRD)** - A Systems Requirements Document (SRD) outlines the functional and performance requirements for a system being developed or used by a NASA research activity. It's a crucial document that ensures the system meets NASA's specific needs and standards. This document will capture, at a minimum, system level requirements in an excel sheet but may be updated to include decomposed subsystem level requirements.
- **Interface Control Document (ICD)** - The ICD is a formal document that defines and controls the interface between two or more systems or components. It specifies the details of how these entities will interact, including their inputs, outputs, and protocols. The SWIFT ICD will capture and define, at a minimum, interfaces with external systems and subsystem to subsystem interfaces.
- **Configuration Management Plan (CMP)** - The CMP contains the details and processes of identifying, controlling, managing changes, and documenting baselines for the SWIFT GMATT vehicle. Up to date configurations of all the documents described in this section are managed per this plan.
- **Technical Specifications** - Detailed documents outlining specifications of flight systems, airframe, and operations. Specifications outline capabilities of individual component, subsystem-level, and system-level capabilities of flight systems and initial test platform (GMATT).
- **Decision Memos (DM)** - Documents decisions made regarding flight system components, protocols, and methodologies. Important for documenting rationale, technical capability, and providing source for future designers to understand purpose of flight systems design.
- **Test Procedures (TP)** - Procedures outlining scope, references, system overview, safety, test checklist, and expected results for component-level and system-level verification and validation testing.

9 Conclusions

The SWIFT research activity is aimed at establishing a cost-effective UAS research capability that supports rapid, flexible flight research across multiple platforms. The systems engineering efforts outlined in this document show the strategic development of a vehicle-agnostic, scalable architecture, allowing various platforms to use standardized infrastructure for flight research. This initiative prioritizes stakeholder needs such as low cost flight opportunities and expediting high-risk research concept to flight. The GMATT platform is leveraged as a development platform to showcase this scalable architecture, facilitating a wide array of research activities while emphasizing subsystem innovation and minimizing platform-level risks.

This document details essential technical processes, organizational strategies, and resource allocations, serving as a comprehensive guide for technical integration and execution. It ensures effective risk reduction, rapid experimentation, and the integration of new flight systems. By encouraging a tailored approach to systems engineering, this systems engineering approach accommodates the unique challenges of small/mid-scale, time-constrained projects, ensuring safety, compliance, and alignment with stakeholder expectations. This approach supports the development of innovative subsystems that enhance midscale UAS capabilities, contributing significantly to NASA's aeronautics research efforts.

Acknowledgments

We would like to express our sincere gratitude to CAS project management for their generous funding of the SWIFT research activity. We also extend our appreciation to the AFRC Chief Engineering Office and the Airworthiness Office for their invaluable collaboration and insightful input throughout the research activity. Lastly, we would like to thank the dedicated SWIFT team for their exceptional engineering support and commitment to excellence.

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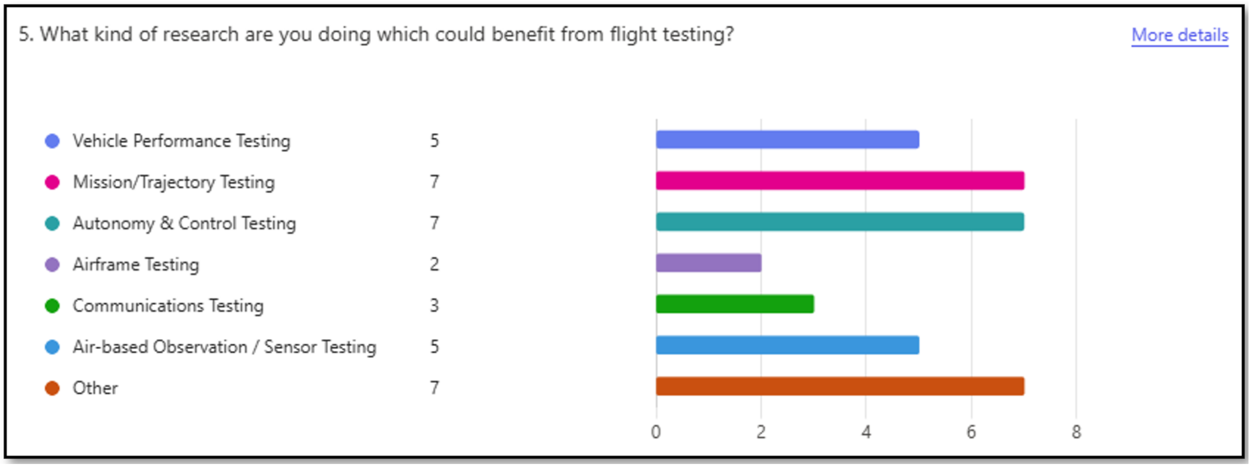
Appendix A

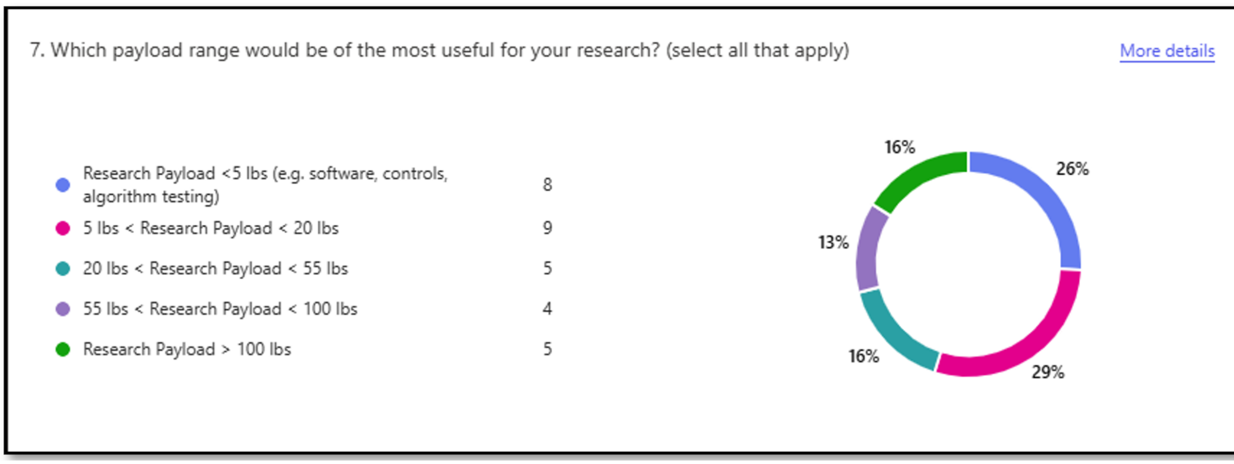
Stakeholder Survey Summary

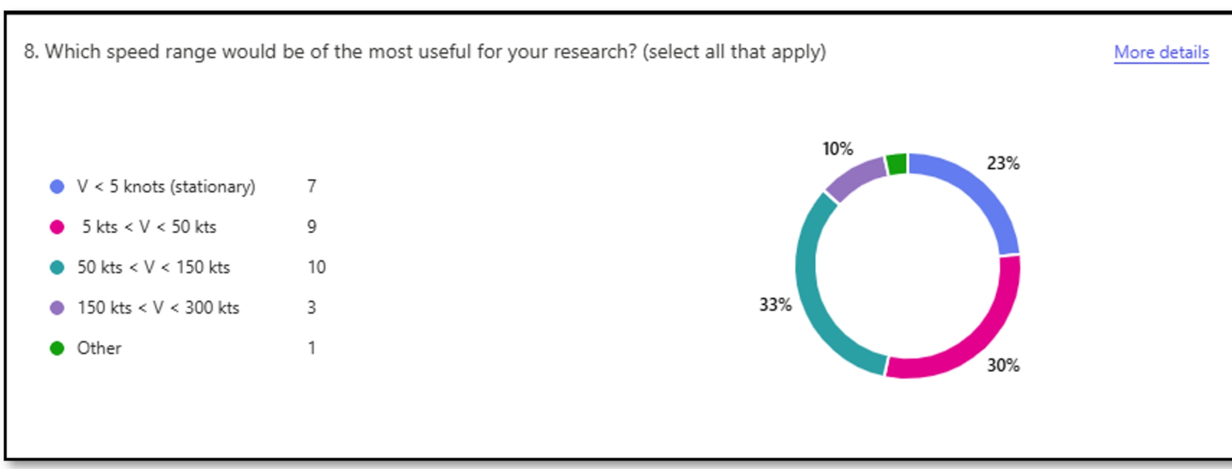
Gathering input from potential flight research customers within NASA is critical to suitably align the stakeholder needs with the capabilities of the SWIFT envisioned flight research future. The survey collected information in early 2025 to inform system level decisions for the overall SWIFT research activity as well as individual flight vehicle designs. Questions were written to solicit feedback about characteristics such as vehicle size, speed, and type as well as advanced capabilities like data acquisition and maneuverability performance. Additional questions were included to shed light on programmatic desires pertaining to schedule, cost, and risk tolerance. The prompts are as follows:

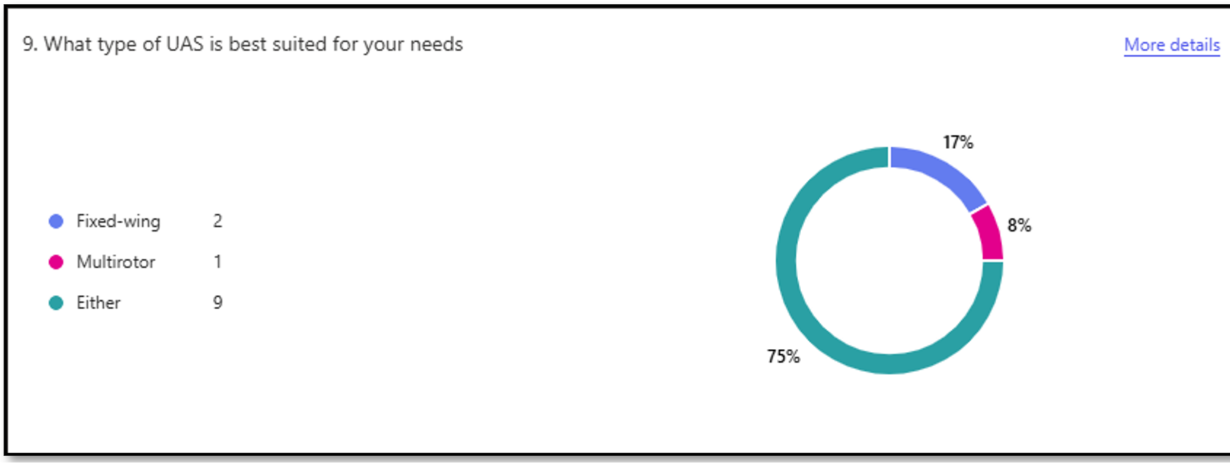
1. Name
2. Organization
3. Project
4. Title of Research Activity
5. What kind of research are you doing which could benefit from flight testing?
6. Please describe what your research is and how it will benefit from flight testing.
7. Which payload range would be of the most useful for your research?
8. Which speed range would be of the most useful for your research?
9. What type of UAS is best suited for your needs?
10. Are you in need of an enduring test capability, or a one-off flight test campaign?
11. When planning a flight test, what is an ideal turn-around time from kickoff to flight?
12. Do you have an anticipated budget for flight testing? If so, what is it?
13. If you intend to fly custom hardware, what is the cost of the hardware?
14. Without SWIFT what other options would you use to get your test in the air?
15. Preference for where the test will occur.
16. Are there any specific performance requirements which you require a flight test capability to meet? If yes, please describe below.

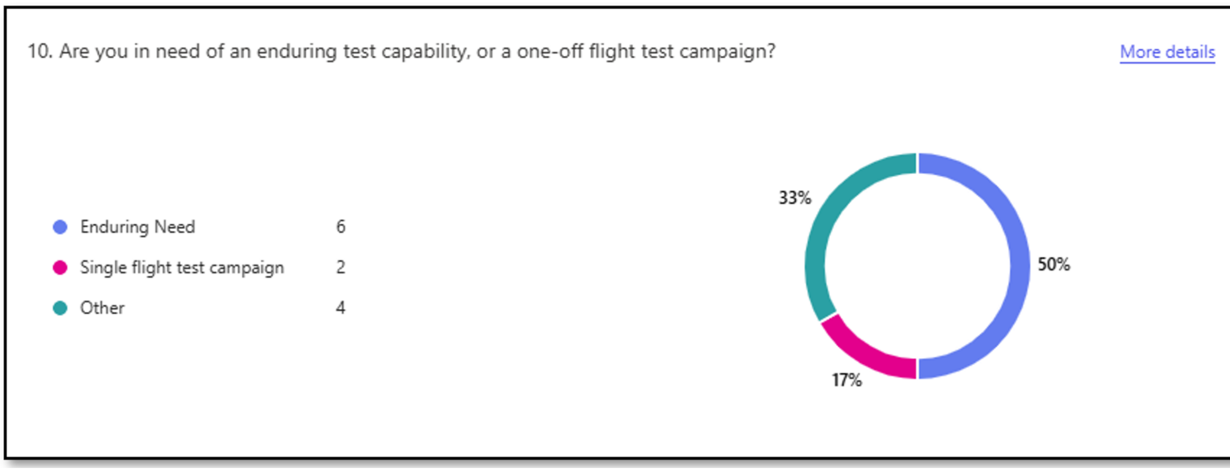
For anonymity, questions 1-4 will not be presented as they relate to the researcher identity and were used to assess coverage of ARMD programs and all four NASA aeronautics centers. Of the roughly 50 researchers contacted, 12 were interested in this type of work and wanted to participate in the survey. Responses to the multiple-choice questions are shown below with key quotes from the extended response questions are presented below.

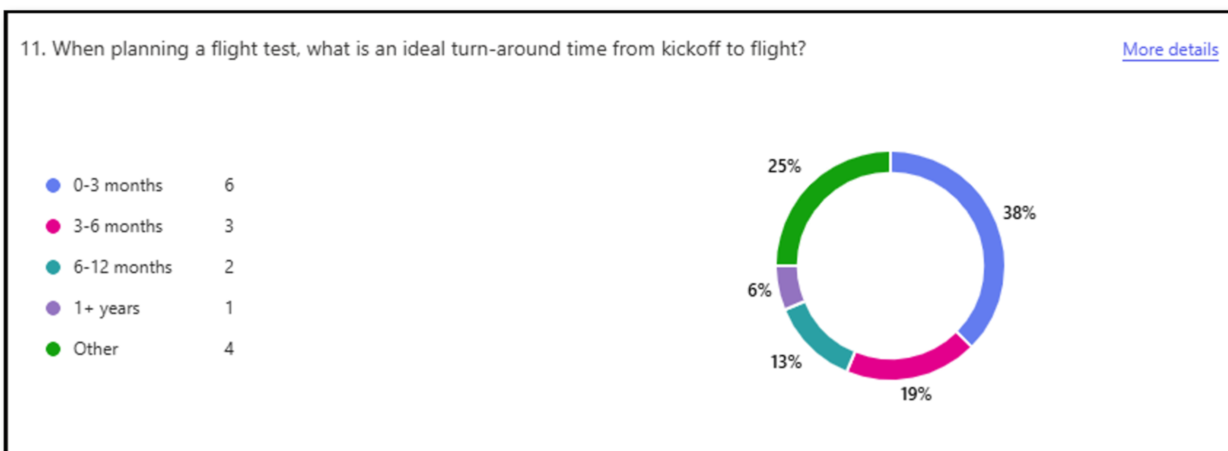

5. What kind of research are you doing which could benefit from flight testing?
More details
Vehicle Performance Testing 5
Mission/Trajectory Testing 7
Autonomy & Control Testing 7
Airframe Testing 2
Communications Testing 3
Air-based Observation / Sensor Testing 5
Other 7
0
2
4
6
8

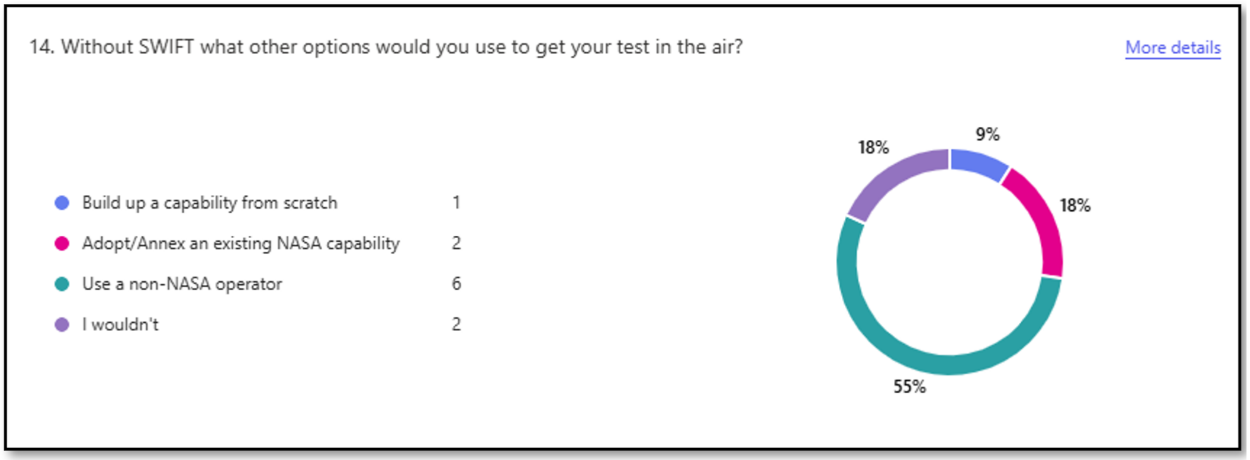

7. Which payload range would be of the most useful for your research? (select all that apply)
More details
Research Payload <5 lbs (e.g. software, controls, algorithm testing) 8
5 lbs < Research Payload < 20 lbs 9
20 lbs < Research Payload < 55 lbs 5
55 lbs < Research Payload < 100 lbs 4
Research Payload > 100 lbs 5
16%
26%
13%
16%
29%

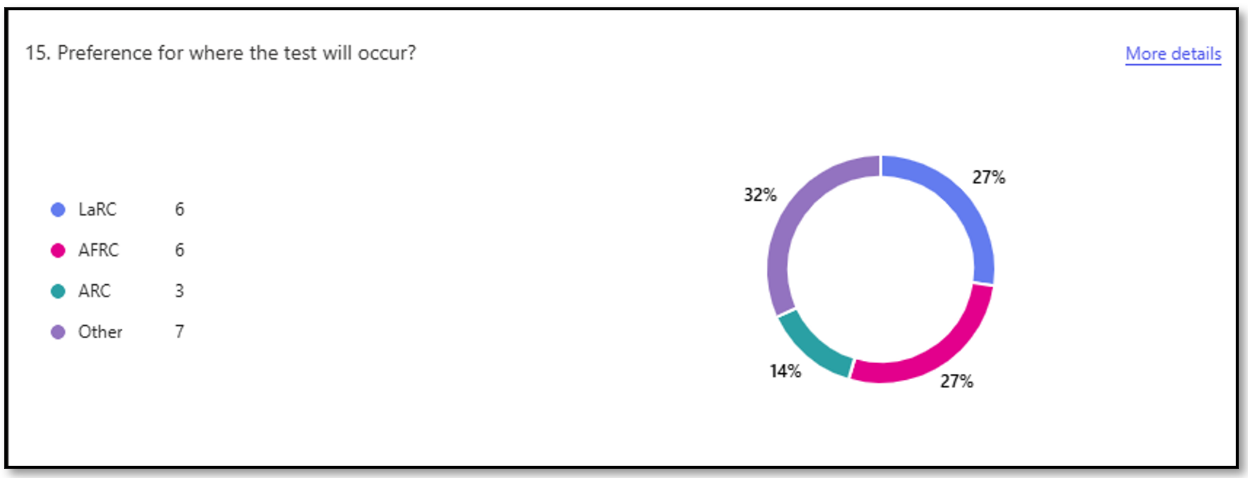

8. Which speed range would be of the most useful for your research? (select all that apply)
More details
V < 5 knots (stationary) 7
5 kts < V < 50 kts 9
50 kts < V < 150 kts 10
150 kts < V < 300 kts 3
Other 1
10%
23%
33%
30%


9. What type of UAS is best suited for your needs
More details
Fixed-wing 2
Multirotor 1
Either 9
17%
8%
75%


10. Are you in need of an enduring test capability, or a one-off flight test campaign?
More details
Enduring Need 6
Single flight test campaign 2
Other 4
33%
50%
17%


11. When planning a flight test, what is an ideal turn-around time from kickoff to flight?
More details
0-3 months 6
3-6 months 3
6-12 months 2
1+ years 1
Other 4
25%
38%
6%
13%
19%





From the open response questions the following key quotes are noted:

- There is a niche between quadrotor flights in academia and NTPS assets like X-62 VISTA. NASA can fill this niche with appropriate inexpensive assets, building on what SWIFT is trying to do. This would be highly utilized not just by NASA projects but outside entities as well. But we have to change the slow and laborious process and create modular, easily updatable architecture on a stable of airframes.
- Dual flight control architecture that includes a companion research computer with GPUs running at a minimum of 200 Hz, preferably much faster, modular architecture to allow for rapid upgrades in both companion computer, sensor and more importantly software.
- Flight data sample rate greater than 50 Hz; availability of a companion computer.
- Autonomous flight for eVTOL UAM vehicles under realistic contingencies - simulations are not sufficient to show relevant environment performance for technology maturation purposes. Rapid, persistent testing of new algorithms with minimum V&V is required.
- Need a flight test asset with relevant configuration, at relevant scale, with known, public data, able to accept higher risk research, with ability to invasively integrate hardware and software.
- There is a need for flight test on aircraft that are at least about 1000 lb with configurations relevant to AAM, in order to perform research at a size scale that is relevant to passenger carrying AAM - the current solution path to this is via partnership with the FDC project on

Open eVTOL / RAVEN.
- Having an equivalent system to SOFRS for UAS would be beneficial for the Science Directorate.
- The ability to have direct control of the airframe/surfaces and to integrate novel sensors and sensor fusion algorithms into control loops.
- Some stakeholders need AAM-representative approach and landing trajectories, relative to ground and elevated-platform vertiports. Altitudes start at 2000ft AGL and end at landing. Speeds start at 150kts and end at hover. Other scenarios are generally 500ft AGL to 5000ft AGL, 80-150 knots. Day, twilight, and night. Clear and degraded visibility. Payload volume is roughly 1 to 2 cubic ft. Unobstructed forward and downward fields of view for cameras and lidar. Companion computers are still being evaluated, but hardware video compression is desired. Currently testing Jetson AGX Orin. DGPS such as RTK is desired, but it part of the payload if not provided by the platform aircraft. High throughput datalink with wide geographic coverage is desired, such as Starlink.
- Five days of high frequency iteration, with flight tests running touch-and-goes on a small attritable vehicle would help me better prepare my algorithms than a year's worth of simulation development and may lead to better simulations in the meantime.
- Standard robotics capabilities: actuator controllers run at 20kHz, actuator position feedback at greater than 1KHz, low level control run on dedicated processor greater than 500 Hz, planning/machine learning runs on companion computer at about 100Hz.

The following themes were gleaned from the survey responses:
- Aeronautics research requires a system that can transition rapidly from conceptual design to experimentation with researchers prominently desiring turnaround times in the 0–6-month range.
- A platform-agnostic and modular approach is essential, allowing for diverse research objectives and accommodating uncrewed aircraft systems (UAS) of different types and sizes. Central to the initiative is a standardized, scalable architecture designed to support multiple projects across different research domains.
- Researchers express a need for test assets with relevant configurations, sizes, and capabilities to perform realistic, scenario-driven research.
- The survey identifies a gap in current research capabilities between academia and large-scale assets like NTPS and emphasizes the potential for NASA to fill this niche.
- Desirable features include modular architectures, high-frequency iteration capabilities, and the integration of companion research computers with GPUs.
- Effective but minimal flight vehicle platforms with high performing data acquisition and control systems was a common theme.
- Researchers outline specific performance needs such as flight data acquisition rates, maneuverability, altitude, speed, and payload capacities to improve existing processes.
- There is a need for robust communication links and integration of advanced technologies for effective testing and data acquisition.
- Researchers highlight the importance of collaboration with existing projects for larger aircraft configurations, relevant to Advanced Air Mobility (AAM).

Overall, the SWIFT research activity is viewed as a much-needed advancement in flight research capability, addressing both current limitations and future needs through strategic flexibility, advanced infrastructure, and tailored methodologies. The positive feedback from the survey underscores the project's potential impact in filling an important niche in aeronautics research. While achieving all the research requests is not feasible, a design aimed at addressing 80% of these requests would strike a balance between system feasibility and desirability. This survey suggests SWIFT should develop capabilities that prioritize schedule speed over vehicle performance. Beyond vehicle design, a strong desire for simple flight vehicles with high quality data acquisition is apparent.

Appendix B

Technical Review Entry and Exit Criteria

- **Mission Concept Review/System Requirements Review Entry Criteria**:
  1. An agenda for the MCR/SRR, success criteria, and instructions to the review board have been agreed to by the technical team, the principal investigator, and the review chair prior to the review.
  2. The following primary products are ready for review:
     (a) Program requirements.
     (b) Stakeholders have been identified and stakeholder expectations have been defined and are ready to be baselined after review comments are incorporated.
     (c) The concept has been developed to a sufficient level of detail to demonstrate a technically feasible solution to the mission/research activity needs and is ready to be baselined after review comments are incorporated.
     (d) MOEs and any other mission success criteria have been defined and are ready to be approved.
  3. Top program risks with significant technical, health and medical, system security (including cybersecurity), safety, cost, and schedule impacts have been identified along with corresponding mitigation strategies
  4. An approach for verifying compliance with program requirements has been defined.
  5. Procedures for controlling changes to program requirements have been defined and approved.
  6. Other program SRR technical products have been made available to the cognizant participants prior to the review:
     (a) Mission/research activity goals and objectives that are ready to be baselined after review comments are incorporated.
     (b) Alternative concepts that have been analyzed and are ready to be reviewed.
     (c) Preliminary mission descope options.
     (d) Preliminary approach to verification and validation for the selected concept(s).
     (e) Preliminary engineering development assessment and technical plans to achieve what needs to be accomplished in the next phase.
     (f) Preliminary traceability of program-level requirements on research activities to the Agency strategic goals and Mission Directorate requirements and constraints.
     (g) Initial risk mitigation plans and resources for significant technical risks.
     (h) Preliminary cost and schedule
     (i) Review Plan ready to be baselined after review comments are incorporated.
     (j) Preliminary Configuration Management Plan.
     (k) Preliminary TMP (or equivalent program documentation) for uncoupled, loosely coupled, tightly coupled, and two-step AO programs.
     (l) RF (radio frequency) spectrum requirements have been identified.
- **Mission Concept Review/System Requirements Review Exit Criteria**:
  1. Mission objectives are clearly defined and stated.
  2. The selected concept(s) satisfactorily meets the stakeholder expectations.
  3. The mission is feasible. A concept has been identified that is technically and logistically feasible. A rough cost estimate is within an acceptable cost range.
  4. The need for the mission has been clearly identified.

5. Alternative concepts have adequately considered the use of existing assets or products that could satisfy the mission or parts of the mission.
6. Technical planning is sufficient to proceed to the next phase and includes planning for hardware, software, human systems, and data deliverables.
7. Risk and mitigation strategies have been identified and are acceptable based on technical risk assessments.
8. Definition of external system interfaces is adequately mature and approved.
9. The program cost and schedule estimates are credible to meet program requirements.
10. Top risk identification is complete and mitigation strategies appear reasonable.
11. The responsible Center spectrum manager at the responsible Center was notified of preliminary requirements.
12. Proposed tailoring is appropriate and consistent with applicable Agency and Center guidance.

- **Tabletop Technical Review Entrance Criteria**:
  1. A preliminary TTR agenda, success criteria, and instructions to the review board have been agreed to by the technical team, principal investigator, and review chair prior to the TTR.
  2. All planned lower-level TTRs and peer reviews have been successfully conducted, and RID/RFA/Action Items have been addressed with the originator or designated TA.
  3. The following primary products are ready for review:
     (a) A preliminary design that can be shown to meet all technical requirements and performance measures or has waivers.
     (b) Baselined integration plans
     (c) Baselined Verification and Validation Plan
  4. Other TTR technical work products (as applicable) for hardware, software, and human system elements have been made available to the cognizant participants prior to the review:
     (a) Subsystem design specifications (hardware and software), with supporting trade-off analyses and data, as required, that are ready to be baselined after review comments are incorporated.
     (b) Status of technical performance related to margins, TPMs, and resolution of the previous review discrepancies addressing effectiveness of technical achievement and communicating the overall risk to the research activity.
     (c) Updated risk assessment and mitigation.
     (d) Applicable design standards that have been identified and incorporated.
     (e) Interface control documents that are ready to be baselined after review comments are incorporated.
     (f) Verification/validation plan that is ready to be baselined after review comments are incorporated.
     (g) Updated technical resource utilization estimates and margins.
     (h) Updated TMP (or equivalent program/research activity documentation).
     (i) Software criteria and products, per NASA-HDBK-2203.
     (j) Design and requisite data submitted to Center/facility spectrum manager for preparation of request at least 10 days prior to TTR.
     (k) List of potential single point failures.
- **Tabletop Design Review Exit Criteria**:
  1. The top-level requirements, including mission success criteria, TPMs, and any sponsor-imposed constraints, are agreed upon, finalized, stated clearly, and consistent with the

preliminary design.

2. The flow down of verifiable requirements is complete and proper, or, if not, an adequate plan exists for timely resolution of open items. Requirements are traceable to parent technical requirements and to mission goals and objectives.
3. The preliminary design is expected to meet the requirements at an acceptable level of risk and with acceptable margins.
4. Definition of the system interfaces (both external entities and between internal elements) is consistent with the overall technical maturity. Associated risks, including system security, have been identified and represent an acceptable level of risk.
5. Any required new technology has been developed to an adequate state of readiness, or backup options exist and are supported to make them viable alternatives.
6. The risks are understood and have been credibly assessed, and plans, a process, and resources exist to effectively manage them.
7. Safety and mission assurance (e.g., safety, reliability, maintainability, quality controls, quality verifications, supplier risk management, and Electrical, Electronic, and Electromechanical (EEE) parts) have been adequately addressed in preliminary designs and any applicable SMA products (e.g., PRA, system safety analysis, and failure modes and effects analysis) meet requirements, are at the appropriate maturity level for this phase of the program/research activity life cycle, and indicate that the safety/reliability residual risks will be at an acceptable level.
8. Adequate technical and programmatic margins (e.g., mass, power, memory) and resources exist to complete the development within budget, schedule, and known risks.
9. The operational concept is technically sound, includes (where appropriate) human systems, and includes the flow down of requirements for its execution.
10. Technical trade studies are mostly complete to sufficient detail and remaining trade studies are identified, plans exist for their closure, and potential impacts are understood.
11. TBD and TBR items are clearly identified with acceptable plans and schedule for their disposition.
12. Preliminary analysis of the primary subsystems has been completed and summarized, highlighting performance and design margin challenges.
13. Appropriate modeling and analytical results are available and have been considered in the design.
14. Heritage designs have been suitably assessed for applicability and appropriateness.
15. Manufacturability has been adequately included in design.
16. Concurrence by the responsible Center spectrum manager that the research activity has provided requisite RF system data.
17. Procurement and supply chain risk management execution is complementary with the technical development schedule.

- **System Integration Review Entrance Criteria**:
  1. The research activity has successfully completed the previous planned life-cycle reviews, and all Requests for Actions (RFAs) and Review Item Discrepancies (RIDs) have been addressed and resolved or a timely closure plan exists for those remaining open.
  2. A preliminary SIR agenda, success criteria, and instructions to the review board have been agreed to by the technical team, principal investigator, and review chair prior to the SIR.
  3. Integration plans baselined at TTR that have been updated and approved.
  4. System integration and interface ground test plans.
  5. Status of technical performance related to margins, TPMs, and resolution of the previous

review discrepancies addressing effectiveness of technical achievement and communicating the overall risk to the research activity.

6. Mechanical and electrical interface requirements for hardware necessary to start system integration have been verified in accordance with the interface control documentation and plans for verification of remaining hardware exist.
7. All functional, unit-level, subsystem, and qualification testing has been conducted successfully or is on track to be conducted prior to scheduled integration.
8. Other SIR technical products (as applicable) for hardware, software, and human system elements have been made available to the cognizant participants prior to the review:
   (a) Updated design solution definition.
   (b) Updated interface definition(s).
   (c) Updated verification and validation plans.
   (d) Procurement status including Supply Chain Risk Management (SCRM) activities (e.g., audits and assessments, Government-Industry Data Exchange Program (GIDEP), counterfeit avoidance).

- **System Integration Review Exit Criteria**:
  1. Integration plans and procedures are on track for completion and approval to support system integration.
  2. Previous component, subsystem, and system test or analysis results form a satisfactory basis for proceeding to integration.
  3. Risks are identified and accepted by leadership, as required.
  4. TBD and TBR items are clearly identified with acceptable plans and schedule for their dispositions.
  5. The integration procedures and workflow have been clearly defined and documented or are on schedule to be clearly defined and documented prior to their need date.
  6. Software components meet the success criteria defined in NASA-HDBK-2203.
- **Flight Readiness Review Entrance Criteria**:
  1. The system and support elements are ready and have been properly configured for flight/mission operations.
  2. System and support element interfaces have been demonstrated to function as expected.
  3. The system state supports a launch decision based on the established go/no-go criteria.
  4. The following primary products are ready for review:
     (a) Final certification for flight/use.
     (b) Baselined V&V results.
  5. Other MRR/FRR technical products have been made available to the cognizant participants prior to the review:
     (a) Updated as-built hardware and software documentation.
     (b) Updated operations procedures.
  6. All requisite spectrum (radio frequency) authorizations are in place.
  7. Updated list of all single point failures and their effects
- **Flight Readiness Review Exit Criteria**:
  1. The flight vehicle/system is ready for flight/mission operations.
  2. The hardware is deemed acceptably safe for flight/mission operations.
  3. Certification that flight operations can safely proceed with acceptable risk has been achieved.
  4. Flight and ground software elements are ready to support launch and flight operations.
  5. Interfaces have been checked and demonstrated to be functional.
  6. TBD and TBR items are resolved.

7. The flight and recovery environmental factors are within constraints.
8. All open safety and mission risk items have been addressed, and the residual risk is deemed acceptable.
9. Supporting organizations are ready to support flight/mission operations.
10. Responsible Center spectrum manager(s) concur that all necessary spectrum certification(s) and authorization(s) have been obtained.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704–0188*

1. REPORT DATE *(DD-MM-YYYY)*
01-12-2025

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
The Systems Engineering Approach to the Streamlined Workflow for Innovative Flight Test Activity

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
David Rinehart
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Matthew Gray
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
533127.02.23.03.04

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Glenn Research Center
Brook Park, Ohio 44135

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM–20250009540

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category
Availability: NASA STI Program (757) 864-9658

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This paper presents the Systems Engineering approach to the Streamlined Workflow for Innovative Flight Test (SWIFT) research activity, which aims to establish a cost-effective uncrewed aircraft research capability that facilitates rapid and flexible flight research across diverse platforms. The initiative focuses on developing a scalable, vehicle-agnostic architecture that enables standardized infrastructure for flight research, expediting the transition from concept to flight, particularly for high-risk technologies. Utilizing an existing NASA flight platform as a development testbed, the research activity emphasizes subsystem innovation while minimizing risks associated with platforms and infrastructure. Key components include advanced avionics, data acquisition systems, and modular designs that support a wide range of research applications. The research activity incorporates a tailored systems engineering approach to ensure compliance with airworthiness requirements, foster stakeholder engagement, and maintain traceability to NASA needs and research activity objectives. Ultimately, the SWIFT research activity aims to enhance midscale uncrewed aerial system capabilities, significantly contributing to NASA's aeronautics research objectives.

15. SUBJECT TERMS
keywords

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	00	HQ-STI-infodesk@mail.nasa.gov (757) 864-9658

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18