U.S. Department of Transportation
Federal Aviation Administration

FINAL PROJECT REPORT

Form Approved:
O.M.B. No. 2120-0559
9/30/2013

PART I - PROJECT IDENTIFICATION INFORMATION

1. Institution and Address Georgia Tech Research Corporation	2. FAA Program Environment and Energy	3. FAA Award Number 13-C-AJFE-GIT-066
505 Tenth Street NW Atlanta, GA 30332-0420	4. Award Period From 6/5/20 To 09/30/25	5. Cumulative Award Amount $1,000,000

6. Project Title
ASCENT Project 061: Noise Certification Streamlining

PART II - SUMMARY OF COMPLETED PROJECT (For Public Use)

Noise certification procedures (with their inclusion of equivalent procedures) have served aviation stakeholders (i.e., original equipment manufacturers [OEM], regulators, operators, airports, etc.) well since the 1960s. With new vehicle types and new technologies (including new entrants, digital technologies for airframes, propulsion, and measurements, etc.), it is necessary to critically examine the existing certification processes. Key features of current certification practices include equivalent procedures and supporting technology, which many OEMs utilize 14 C.F.R. § 36 (2025). Equivalent procedures are anticipated for both existing and new standards to further accommodate innovation in the future. The project objective is to examine current noise certification procedures and identify opportunities to streamline the noise certification process while recommending process updates and revised/new standards for building the flexibility needed to accommodate all air vehicle types. ASCENT Project 061 seeks to propose quantifiable process improvements and facilitate the application of traditional systems engineering and MBSE, while leveraging these methods for the management of regulatory requirements. To perform the proposed research under this effort, Georgia Tech has teamed with several industrial partners with extensive experience in noise certification. Each industrial partner brings expertise for different types of vehicles, such as large subsonic transports, propeller-driven small aircraft, and rotorcraft.

PART III - TECHNICAL INFORMATION (For Program Management Uses)

1. **ITEM** (Check appropriate blocks)	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM	
				Check (X)	Approx. Date
a. Abstracts of Theses	✘				
b. Publication Citations		✘			
c. Data on Scientific Collaborators	✘				
d. Information on Inventions	✘				
e. Technical Description of Project and Results				✘	
f. Other (specify)					

2. Principal Investigator/Project Director Name (Typed) Dimitri Mavris	3. Principal Investigator / Project Director Signature Dimitri Mavris	4. Date 10/31/2025

FAA Form 9550-5 (03-03) Supersedes Previous Edition

List of ASCENT Project 061 Publications

- Ali, Hussein E., Balaji Ravikanti, Michael G. Balchanos, Evan Harrison, and Dimitri Mavris. "MBSE Enabled Requirement Verification for a Traceable Regulatory Analysis Framework of UAS Noise Certification Standards." In *AIAA SCITECH 2025 Forum*, p. 0367. 2025.
- Mali, Hajar, Nathnael F. Geneti, Michael G. Balchanos, Evan Harrison, and Dimitri Mavris. "A Process Evaluation and Visualization Framework for Unmanned Aerial System (UAS) Noise Certification Testing." In *AIAA SCITECH 2025 Forum*, p. 0368. 2025.
- Balchanos, Michael, Balaji Ravikanti, Hussein Ali, Hajar Mali, Evan Harrison, and Dimitri N. Mavris. *A Regulatory Analysis and Process Improvement Decision Support Framework for Unmanned Aerial System (UAS) Noise Certification*. No. QD24_submission_128. University of Salford, 2024.
- Balchanos, Michael G., Mali Hajar, Rahul Rameshbabu, Evan Harrison, and Dimitri N. Mavris. "A Process Improvement Model and Visualization Environment for Unmanned Aerial System (UAS) Noise Certification Flight Testing." In *AIAA SCITECH 2024 Forum*, p. 1626. 2024.
- Ravikanti, Balaji, Hussein Ali, Michael G. Balchanos, Evan Harrison, and Dimitri N. Mavris. "MBSE-Enabled System Verification of Unmanned Aerial System (UAS) Noise Certification." In *AIAA SciTech 2024 Forum*, p. 1627. 2024.
- Kim, Daewoon, Meric Taneri, Ehiremen N. Omoarebun, Michael G. Balchanos, and Dimitri N. Mavris. "MBSE-Enabled System Verification and Process Improvement of Transport Aircraft Certification." In *AIAA SCITECH 2023 Forum*, p. 1897. 2023.
- Kim, Daewoon, Karagoz, Fatma, Datta, Shireen., Balchanos, Michael, Anvid, David, Harrison, Evan, and Dimitri N. Mavris (2022). A Model Based Systems Engineering Approach to Streamlined Noise Certification of Transport-type Aircraft. In 33rd Congress of International Council of the Aeronautical Sciences ICAS, Stockholm, Sweden, 2022.

Project 061 Noise Certification Streamlining

Georgia Institute of Technology

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University Participants

Georgia Institute of Technology (Georgia Tech)

- P.I.s: Dr. Dimitri Mavris and Co-P.I.: Dr. Michael Balchanos
- FAA Award Number: 13-C-AJFE-GIT-066
- Period of Performance: October 1, 2024, to September 30, 2025
- Tasks:
  1. Define Model-Based Standard Framework.
  2. Develop a library of unmanned aircraft systems (UAS) and testing procedures
  3. Document and model noise testing and certification procedures based on existing practices
  4. Develop alternative procedures and assess their performance with existing tools (proof-of-concept)

Project Funding Level

The total amount of current funding from the Federal Aviation Administration (FAA) for ASCENT Project 061 is $250,000 for a 12-month period of performance. The Georgia Institute of Technology has agreed to a total of $83,333 in matching funds.

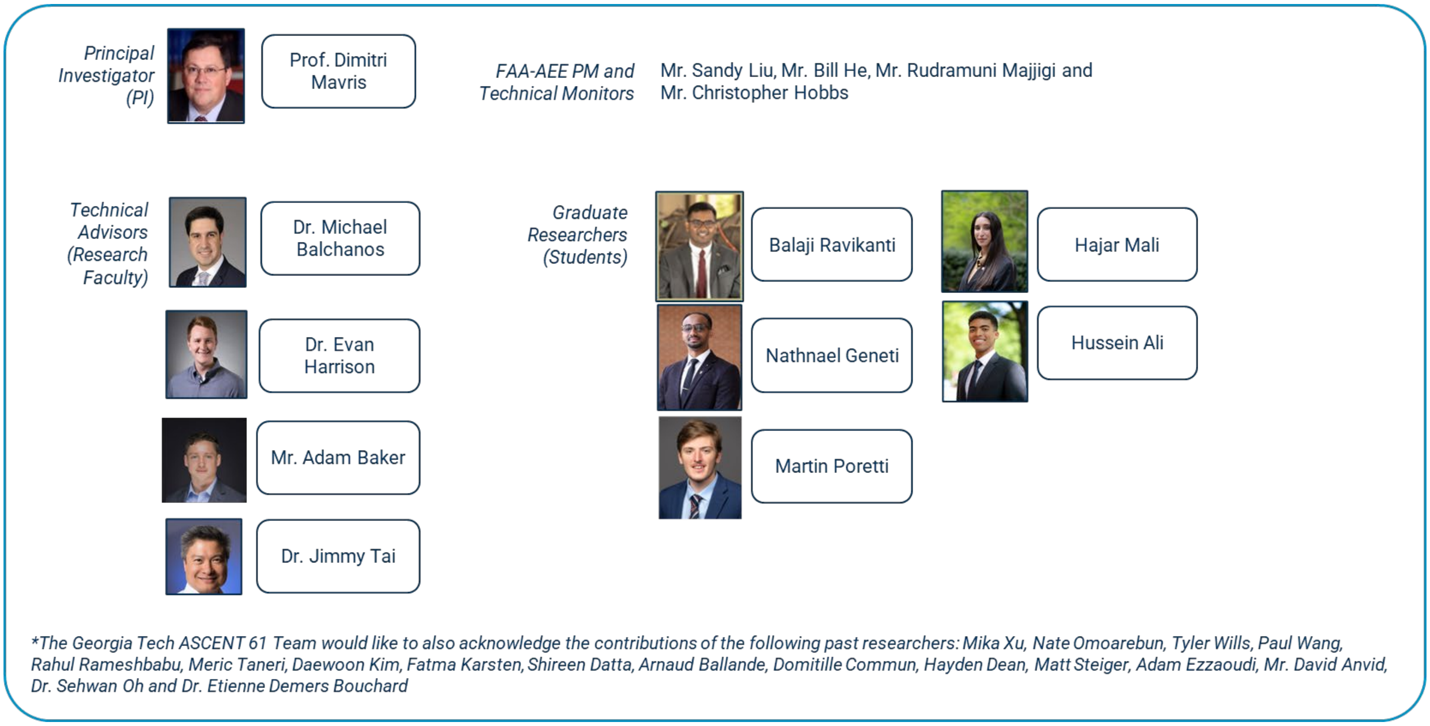
Investigation Team

Georgia Institute of Technology

Prof. Dimitri Mavris, (P.I.), Tasks 1-4
Dr. Michael Balchanos, (co-P.I.), Tasks 1-4
Dr. Adam Baker, (research engineer), Tasks 1-4
Dr. Jimmy Tai, (senior research engineer), Tasks 1-4
Dr. Evan Harrison, (research engineer II), Tasks 1-4
Balaji Ravikanti (graduate student), Tasks 1-4
Hussein Ali (graduate student), Tasks 1-4
Hajar Mali (graduate student), Tasks 1-4

Nathnael Geneti (graduate student), Tasks 1-4
Martin Poretti (graduate student), Tasks 1-4

All team members are affiliated with the Aerospace Systems Design laboratory (ASDL), under the School of Aerospace Engineering at Georgia Tech. Please refer to Figure 1 for a breakdown of the Georgia Tech ASDL Team.



*The Georgia Tech ASCENT 61 Team would like to also acknowledge the contributions of the following past researchers: Mika Xu, Nate Omoarebun, Tyler Wills, Paul Wang, Rahul Rameshbabu, Meric Taneri, Daewoon Kim, Fatma Karsten, Shireen Datta, Arnaud Ballande, Domitille Commun, Hayden Dean, Matt Steiger, Adam Ezzaoudi, Mr. David Anvid, Dr. Sehwan Oh and Dr. Etienne Demers Bouchard

Figure 1. ASCENT Project 061 Georgia Tech Aerospace Systems Design Laboratory (ASDL) team.

Past technical advisors who contributed to the tasks:

- **Mr. David Anvid**, Senior Research Engineer, provided guidance on best practices for noise certification testing, observed and articulated from an industry point of view.
- **Dr. Sehwan Oh**, postdoctoral researcher, focused on exploring current certification regulations, understanding their structure (i.e., hierarchy, associations, etc.) linked to Task 1, and providing input on the application of discrete event and agent-based methods as part of the efforts planned for Task 4.
- **Dr. Etienne Demers Bouchard,** postdoctoral researcher, focused on exploring process modeling methods from literature and formulating a canonical problem to assess the feasibility and applicability of various methods.

Former students who have contributed to the tasks:

- **Ms. Mika Xu,** a second-year Master of Science (MSc) student, contributed to the model-based systems engineering (MBSE) efforts for representing the UAS certification process in systems modeling language (SysML).
- **Mr. Rahul Rameshbabu,** a third year Doctor of Philosophy (PhD) student, supported activities in developing a parametric and interactive decision support tool.
- **Mr. Paul Wang,** a second-year PhD student, was involved in the formulation of a MBSE verification model for UAS.
- **Mr. Daewoon Kim,** a second-year MSc student, was leading the team's MBSE efforts for representing the baseline certification process in SysML.
- **Mr. Nathaniel Omoarebun,** a fifth-year PhD student, was supporting the team's MBSE efforts and SysML modeling activities.
- **Mr. Tyler Wills,** a second-year MSc student, was supporting the team's efforts in process improvement modeling (PIM) methods and process simulation.

- **Mr. Meric Taneri,** a second-year MSc student, was leading the team's efforts in PIM methods, stochastic process simulation (Markov chain Monte Carlo [MCMC]), and interactive visualization.
- **Ms. Shireen Datta,** an MSc student, supported efforts in documenting current procedures and exploring regulation-driven requirements, which are now included in the verification model.
- **Ms. Fatma Karsten,** a PhD student, worked on flight testing plan implementation and an effective perceived noise level (EPNL) calculation module within the MBSE verification model.
- **Mr. Arnaud Ballande**, an MSc student, worked on a process simulation capability for evaluating equivalent procedures under the PIM task.
- **Ms. Hayden Dean,** a PhD student, was instrumental in capturing and understanding current regulations and certification procedures, as dictated by the Certification Procedures for Products and Articles, 14 C.F.R. § 21 (2025), and Noise Standards: Aircraft Type and Airworthiness Certification, 14 C.F.R. § 36 (2025), as well as Advisory Circulars (AC) for Noise Standards: Aircraft Type and Airworthiness Certification, with a particular focus on AC 36-4D (FAA, 2017) and an emphasis on guidance instructions regarding flight testing for noise certification.
- **Ms. Domitille Commun,** a PhD student, worked on implementing a discrete event simulation (DES) model-based process simulation capability for the certification baseline.

Project Overview

Noise certification procedures (with their inclusion of equivalent procedures) have served aviation stakeholders (i.e., original equipment manufacturers [OEM], regulators, operators, airports, etc.) well since the 1960s. With new vehicle types and new technologies (including new entrants, digital technologies for airframes, propulsion, and measurements, etc.), it is necessary to critically examine the existing certification processes. Key features of current certification practices include equivalent procedures and supporting technology, which many OEMs utilize 14 C.F.R. § 36 (2025). Equivalent procedures are anticipated for both existing and new standards to further accommodate innovation in the future. The project objective is to examine current noise certification procedures and identify opportunities to streamline the noise certification process while recommending process updates and revised/new standards for building the flexibility needed to accommodate all air vehicle types. ASCENT Project 061 seeks to propose quantifiable process improvements and facilitate the application of traditional systems engineering and MBSE, while leveraging these methods for the management of regulatory requirements. To perform the proposed research under this effort, Georgia Tech has teamed with several industrial partners with extensive experience in noise certification. Each industrial partner brings expertise for different types of vehicles, such as large subsonic transports, propeller-driven small aircraft, and rotorcraft.

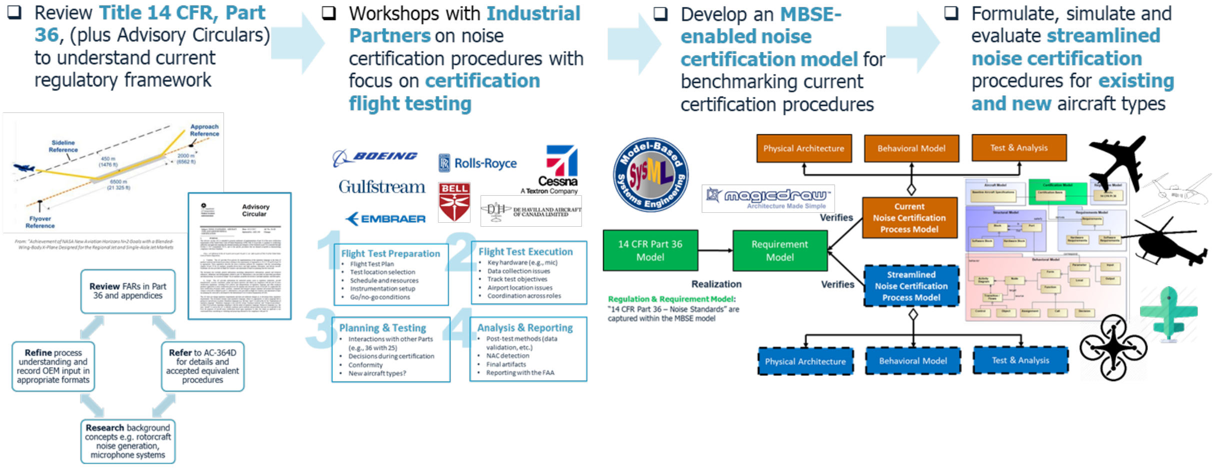


Figure 2. Roadmap toward a model-based framework for exploring current and streamlined noise certification. AC: advisory circular; CFR: Code of Federal Regulations; FAR: Federal Acquisition Regulation; MBSE: model-based systems engineering; NAC: non-acoustical change; OEM: original equipment manufacturer.

The ASCENT Project 061 team is seeking to accomplish the following high-level goals:

- Identify opportunities for increased efficiency (by expediting steps and simplifying processes) and flexibility in current noise certification processes to accommodate multiple vehicle categories.

- Formulate and evaluate revised noise certification processes for current vehicle types and offer recommendations to the FAA (i.e., ACs for Part 36, AC 36-4D [FAA, 2017], etc.).
- Develop process modeling methods to enable quantitative assessments of noise certification.
- Facilitate the application of traditional systems engineering processes for complex systems and MBSE, leveraging these methods for the management of regulatory requirements.
- Leverage the technical expertise acquired in investigating and modeling noise regulatory frameworks and recommend procedures for certification testing and analysis to the FAA for small propeller-driven vehicles and UASs.

Overall ASCENT Project 061 Roadmap and Statement of Work

An overview of the ASCENT Project 061 roadmap toward goals and milestones is shown in Figure 3. The main goal is to provide recommendations to the FAA in the form of feasible equivalent procedures, supported by the latest technologies/hardware, as well as analysis techniques to support the certification of future air vehicle types. These recommendations should be accompanied by evidence that the suggested equivalent procedures are fully in compliance with ACs for Part 36 (FAA, 2017) and use case examples for future air vehicles (e.g., small propeller-driven aircraft and UASs). To implement this roadmap and achieve the targeted outcomes, the team will engage in four main tasks, along with the subtasks that have been prioritized for Year 5 of ASCENT Project 061. These tasks are summarized as follows:

- Task 1: Define Model-Based Standard Framework.
- Task 2: Develop a library of UAS and testing procedures.
- Task 3: Document and model noise testing and certification procedures based on existing practices.
- Task 4: Develop alternative procedures and assess their performance with existing tools (proof-of-concept).

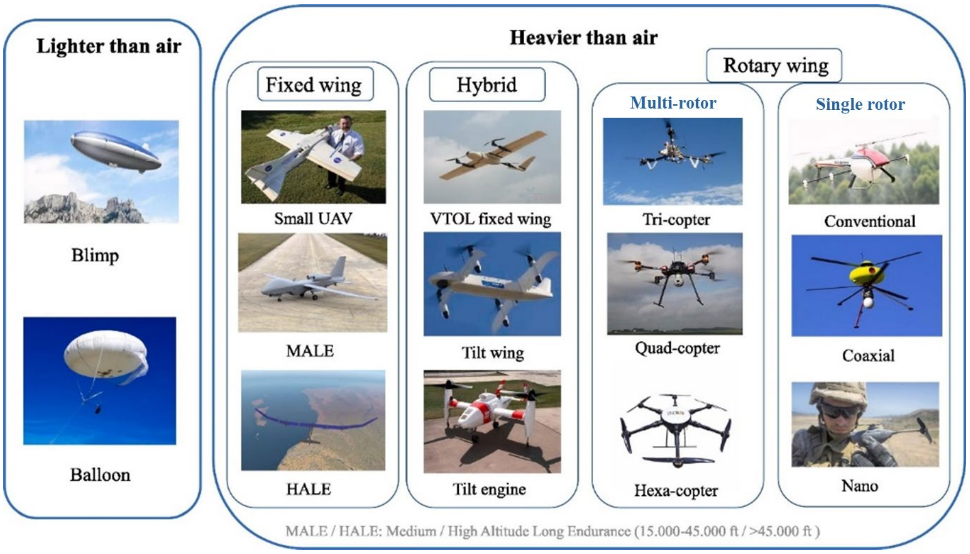


Figure 3. Overview of unmanned aerial system concepts. UAV: unmanned aerial vehicle; VTOL: vertical takeoff and landing.

General Direction for 2024-2025 (Year 5)

The FAA's Office of Environment and Energy (AEE) has suggested a timeframe for pivoting to UAS category certification as part of the year 4 effort (2023-2024). The main task for the Georgia Tech team is to investigate the feasibility and applicability of current ASCENT Project 061 models and analysis tools for exploring procedures and flight test planning to support noise certification of small propeller-driven UAS. To further align with the goals of the Committee on Aviation Environmental Protection (CAEP) Working Group 1 (WG1), the use of the ASCENT Project 061 model-based framework will be demonstrated for standard-setting problems, where decisions on noise standard formulation will be driven by criteria related to the effectiveness of certification rules, as well as the certification testing burden.

Looking ahead, the general direction emphasizes the demonstration of a **standard-setting framework for UAS and urban air mobility (UAM) vehicles** that enables the formulation and evaluation of standards meeting the criteria of being **environmentally beneficial, technically feasible, and economically viable**. This framework is expected to recommend a clear **demarcation between UAS and UAM categories** in terms of standard applicability, reference and test conditions, noise metrics, adjustments, measurement points, test profile procedures, and noise compliance limits. Establishing this structured distinction will ensure that future certification approaches remain scalable and appropriately tailored to the wide range of operational and design characteristics across these vehicle classes.

The above need is motivated by the primary issue with UAS certification, in that the spectrum of possible and available configurations covers a large class of aerial systems with completely different characteristics, as shown in Figure 3. It is assumed to be unlikely that UAS noise certification will be addressed as a “clean-sheet-of-paper” process. Multiple efforts are underway to establish guidance for noise certification similar to that for the transport category. The International Civil Aviation Organization (ICAO) is the recognized authority for developing and establishing a global baseline for noise standards and stringencies, and the harmonization of certification requirements among national airworthiness authorities remains desirable.

Goals and Technical Challenges

The high-level goals for this direction are to: (1) recommend testing procedures for UAS noise certification and, through the proposed methodology; and (2) ensure traceability between regulations, testing requirements, and certification procedures. As part of the planned capability demonstration for the model-based framework, the request for the Georgia Tech research team is to demonstrate the effectiveness of a standard-setting framework for UAS/UAM vehicles enabling the formulation and evaluation of standards that meet criteria of being environmentally beneficial, technically feasible, and economically viable.

Building on this foundation, the 2025 effort expands the scope to **demonstrate a comprehensive standard-setting framework for UAS/UAM vehicles** that directly supports the formulation and evaluation of certification standards meeting the criteria of **environmental benefit, technical feasibility, and economic viability**. This effort aligns with the broader international direction proposed in ICAO CAEP/Steering Group (SG) documentation (CAEP/SG.20221.WP.038.7), emphasizing harmonized and sustainable approaches to emerging aviation sectors.

The key challenges that have been identified and will be addressed by the Georgia Tech research team are as follows:

- There is currently a large spectrum of UAS designs and configurations under testing for production. As the FAA is preparing to release guidance for UAS noise certification, it is important to determine whether the MBSE-enabled method developed under ASCENT Project 061 is sufficiently flexible to accommodate UAS testing actions and to help establish a workflow that meets current and upcoming regulations.
- As there are currently no general regulations and the application of current certification procedures is on a case-by-case basis (e.g., recently completed certification framework for the Matternet® UAS), it is important to assess whether current testing procedures are effective for UASs.

Hence, the FAA is requesting that the ASCENT Project 061 team use the established framework to demonstrate its effectiveness in assisting the FAA through the assessment of Notice of Proposed Rulemaking (NPRM) plans, as these are being iterated before they become approved as part of the UAS noise certification standards.

As a starting point for the literature search, 14 CFR § 36 Appendices G and J are considered the only aircraft noise certification standards that might be applicable for noise certification of small, unmanned aircraft systems (sUAS) in the United States (U.S.), but a number of additional standards will be reviewed and included in formulating certification practices, including the following:

- ICAO Annex 16, Volume 1, Chapters 8, 10, 11, and 13
    - These are applicable to all fixed wing aircraft, rotorcraft, and tiltrotors below a maximum takeoff weight (MTOW) of 3,175 kg.
- NASA Ref. Publication 1258, *Aeroacoustics of Flight Vehicles: Theory and Practice* Volume 1 & 2, August 1991.
- ICAO CAEP Working Paper CAEP/SG.20221.WP.038.7, “UAS/UAM Standard-Setting Framework,”

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Statement of Work/Task Definitions for UAS Noise Certification Research

Following the emphasized focus on UAS certification, the ASCENT Project 061 team further adjusted the statement of work (SOW) towards the development of use cases that address the FAA's needs for UAS noise certification. This SOW is based on the idea of integrating UAS certification goals into the model-based framework, which relies on an MBSE-based capture of the regulatory framework and PIM components. This development will entail the generation of multiple libraries that enable flexibility of use across a broader range of UAS configurations and support traceability between regulations, requirements, and elements of the library.

The tasks that have been implemented under the SOW are the following:

Task 1: Define Model-Based Standard Framework

1.1 Create a comprehensive noise standards database.
1.2 Breakdown the noise standards into logical elements.
1.3 Define a validation process for noise standards.

Task 2: Develop a library of UASs and testing procedures

2.1 Complete technical documentation of UAS configurations.
2.2 Complete technical documentation of UAS noise testing equipment.
2.3 Define UAS noise test plans.
2.4 Define possible simulation techniques.

Task 3: Develop a noise certification procedure based on existing practices

3.1 Transfer noise testing plans to the MBSE model.
3.2 Transfer noise testing data to the MBSE model.
3.3 Develop a full noise test plan.
3.4 Implement a validation process.

Task 4: Develop alternative procedures and assess their performance with existing tools

4.1 Develop alternative testing procedures using the elements library.
4.2 Transfer alternative procedures to the PIM.
4.3 Report on the performance of the alternative procedures.
4.4 Develop a proof-of-concept demonstration of the PIM capabilities.

Framework Demonstration Use Case for Standard Setting

As part of the framework capability demonstration, the ASCENT Project 061 team has scoped a problem that is specific to decision making for standard setting. In contrast to Tasks 1 to 4 listed above that mostly cover the development steps of the framework, the following tasks are specific to the demonstration exercise:

Task D.1: Define Model-Based Standard Framework

- Create a comprehensive database that synthesizes noise standards information from various sources including the FAA, European Union Aviation Safety Agency (EASA), and International Organization for Standardization (ISO).
- Analyze the existing standards to supplement a text-based definition of a standard by (1) identifying the categories of information necessary to sufficiently define a standard and then (2) use them to compare the existing standards.

Task D.2: Evaluate the Applicability of Existing Standards to UAS and UAM Vehicles

- Create a database of noise measurements (from publicly available test campaign data) for a variety of UAS/UAM configurations.
- Conduct a comparative analysis between UAS and UAM vehicles in terms of configuration, weight, operational altitudes, etc.
- Evaluate existing standards pertaining to prescribed test procedure altitude, speed, etc.
- Re-adjust and validate the standard framework once data for UAM vehicles are available.

Task D.3: Incorporate Process Complexity and Test Process Sensitivity Assessment to the Standard-Setting Framework

- Model and simulate the noise certification testing as a stochastic process.
- Quantify and assess the complexity level of the process using a set of complexity metrics.
- Identify trends related to the test conditions (i.e., altitude, speed, and weight).
- Conduct sensitivity analyses (e.g., histogram overlays and prediction profilers) to assess and compare different alternative processes.

Task D.4: Incorporate Economic Viability Assessment to the Standard-Setting Framework

- Conduct a time and cost analysis of the certification processes associated with the proposed standards to evaluate the overall economic impact on applicants to ensure the standards do not impose unnecessary economic burden.

Matrixing of Parallel ASCENT Project Efforts

Within the topic of UAS testing and certification for noise, there are currently three related, but unique, ASCENT research efforts (Figure 4):

- ASCENT Project 077: Measurements to Support Noise Certification for UAS/UAM Vehicles and Identify Noise Reduction (The Pennsylvania State University)
- ASCENT Project 009/094: Geospatially Driven Noise Estimation Module (Georgia Tech ASDL)
- ASCENT Project 061: Noise Certification Streamlining (Georgia Tech ASDL)

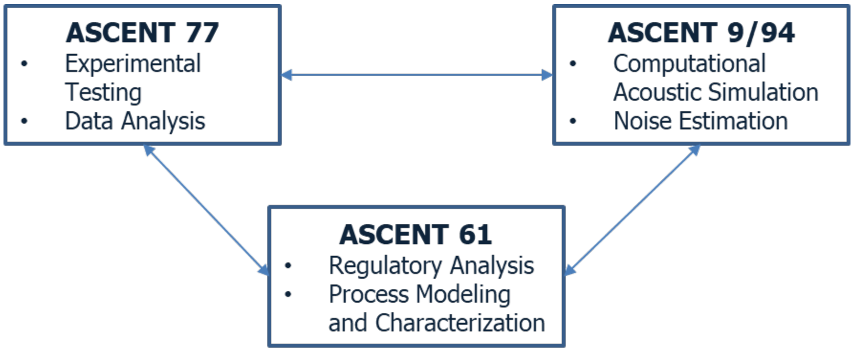

Figure 4. Coordination with parallel ASCENT work related to unmanned aerial system certification.

To preclude "mission creep" into other projects' remit and to leverage the work of the other ASCENT project teams, the ASCENT Project 061 team has been coordinating on a regular basis with ASCENT Project 077 and ASCENT Project 009/094 team members (as highlighted in Figure 4). The main collaboration areas are the following:

- ASCENT Project 077: Data sharing. Experimental test data provide real-world input for noise certification modeling. The results of the ASCENT Project 077 testing efforts provide a better understanding of the most significant parameters affecting UAS noise characteristics. The weighting of these parameters may influence modifications to the existing MBSE model.
  - Comparison of field geometry, test equipment, and basic flight profiles in addition to UAS configuration, weight, and vehicle performance
- ASCENT Project 009/094: Evaluation of possible vehicle operational environments and the practical impacts of noise profiles on the public. While the ASCENT Project 009/094 efforts do not provide direct technical data for MBSE modeling, these efforts do provide context for how noise level outputs from the certification process are applied to an operational environment.

Summary of Major Accomplishments to Date

The following accomplishments have been made to date for ASCENT Project 061:

- Performed a literature search and documented regulations and current testing standards for small UAS (14 CFR § 36 Appendix G, J, and H, and recent NPRMs)
- Completed the **architecting and implementation of a noise certification modeling and assessment framework** for transport and UAS category aircraft.
  - The traceable structure for UAS noise certification requirements uses the MBSE verification model developed for the transport category.
  - The MBSE framework can accommodate multiple UAS types and allows for process effectiveness and flexibility evaluation.
  - Finalized the model-based architecture and delineated key requirements across UAS standards for representation in the knowledge graph.
- Completed **development of the PIM**, which is a key enabling analysis module under the ASCENT Project 061 framework:

  - Developed and implemented metrics with the analysis.
  - Used stochastic Monte Carlo methods for capturing and simulating process uncertainties in the PIM.
  - Applied the PIM as a demonstration example for a typical plan for UAS noise testing to better capture the process and properly estimate the cost, staff, and time implications.
  - Calibrated the model using noise data provided by the 2021 Causey campaign (James et al., 2021).
- Formulated use cases aligned with the needs and recommendations provided by the OEM partners, with a focus on **exploring implications of alternative testing procedures on regulatory compliance.**
  - Focused on **process simplification** (e.g., lateral microphone placement or removal, if trusted analysis is used) for a set of scenarios and experiments.
  - Focused on exploring alternatives **for standard setting** for the overall framework demonstration.
- Reviewed and provided comparison of the UAM noise standards with the UAS standards for demarcation of categories.
- Developed a **visualization environment** in the JMP[®] software to support as a use case demonstrator and decision support environment.
- Published articles with the American Institute of Aeronautics and Astronautics (AIAA) for the SciTech 2025 and participated in the Quiet Drones Symposium 2024.

In the following sections, key contributions are highlighted, along with detailed descriptions of technical progress, research approaches, key milestones, and accomplishments for each task.

References

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ICAO. (n.d., working paper). CAEP/SG.20221.WP.038.7 - UAS/UAM Standard-Setting Framework. Committee on Aviation Environmental Protection.

Task 1 - Define Model-Based Standard Framework

Georgia Institute of Technology

Objectives

In support of the main research objective of ASCENT Project 061 Task 1 focuses on examining current noise standards (Task 1.1) and benchmarking against current industry practices in how these standards are adopted and implemented (Tasks 1.2 and 1.3).

Task 1: Define model-based standard framework
  1.1 Create a comprehensive noise standards database
  1.2 Breakdown the noise standards into logical elements
  1.3 Define a validation process for noise standards

Research Approach

Task 1.1 Create a Comprehensive Noise Standards Database

For Task 1.1, the main goal was to create a comprehensive database that synthesizes noise standards information from various sources including the FAA, EASA, and ISO. The task objective was to gain an understanding of current UAS and UAM noise standard frameworks in terms of their intent and structure. In particular, our team conducted a thorough

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literature review of noise standards for UAS and UAM vehicles that were issued by the FAA, EASA, and ISO. Figure 5 illustrates some of the existing standard references that were explored during this process. A traceable and manageable model-based environment is necessary to keep track of relationships and dependencies between all standards.

Along with the extensive review of existing noise standards, the research team aimed to obtain a fundamental understanding of the noise standard framework starting from the general regulatory intent which is to limit the annoyance to communities where UAS/UAM operate. The generation of standards that can successfully achieve this intent requires an understanding of how UAS/UAM vehicles produce noise and what are the key sound features that represent the human auditory system response. This fundamental understanding will provide the basis for understanding the noise measurement procedures and the choice of noise metrics in the existing noise standards as demonstrated in Figure 6.

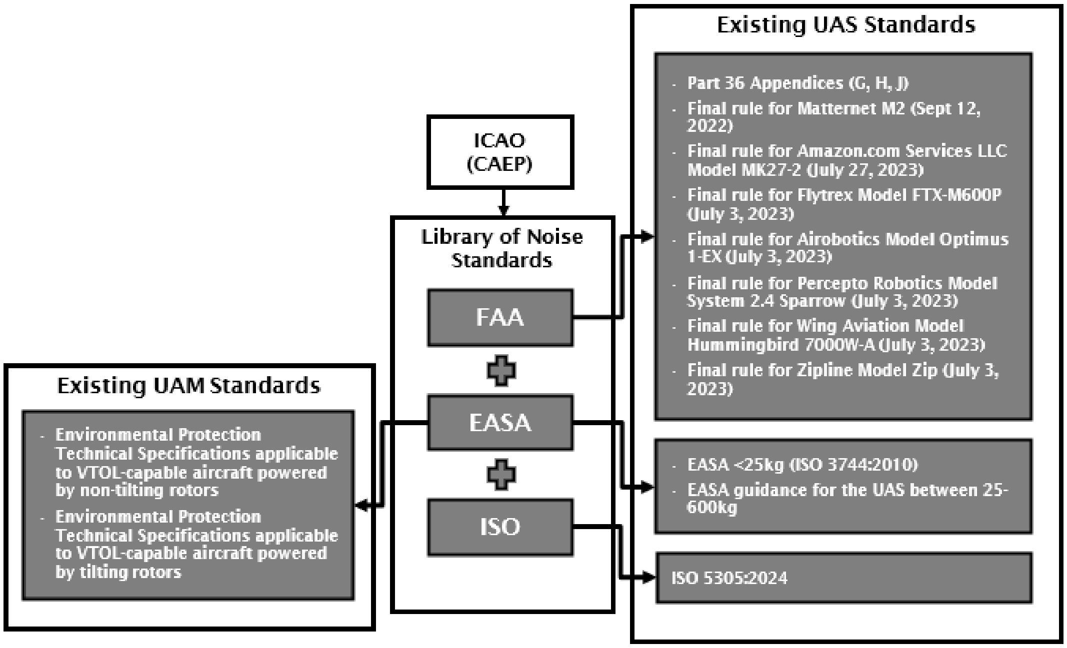

Figure 5. Existing noise standards frameworks. CAEP: Committee on Aviation Environmental Protection, EASA: European Union Aviation Safety Agency, FAA: Federal Aviation Administration, ICAO: International Civil Aviation Organization, ISO: International Organization for Standardization, VTOL: vertical takeoff and landing.

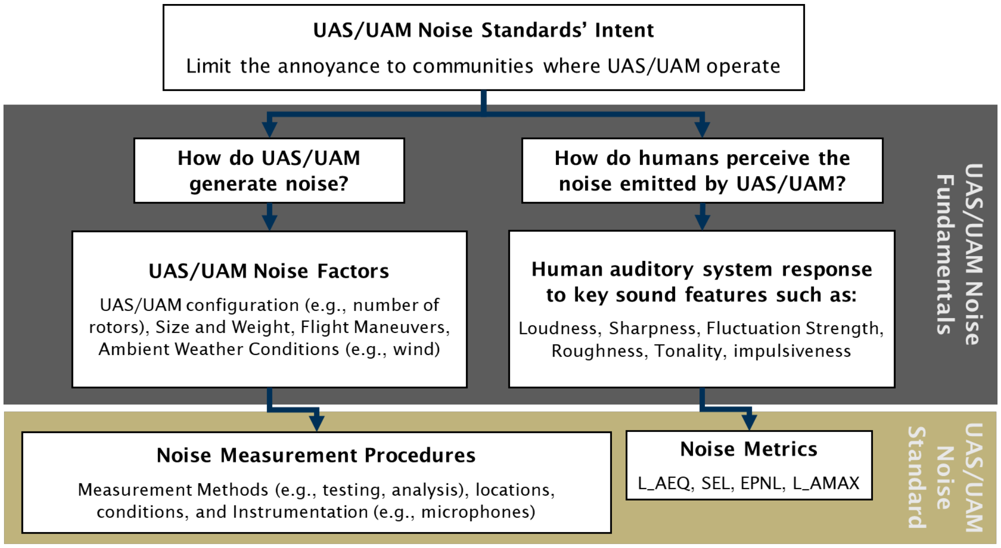

Figure 6. Noise standards intent, noise factors, key sound features and how they relate to the standards. UAM: urban air mobility, UAS: unmanned aircraft system.

Moreover, another motivating factor for creating the noise standards database is to examine the existing body of standards and identify the differences and similarities between them. Figure 7 illustrates a relationship diagram used to visually determine the different associations between the existing standards from different entities. This examination aims to produce two outcomes: (1) establishing a demarcation between UAS and UAM noise standards (as illustrated in Figure 8) and (2) enabling the identification of gaps within current UAS/UAM noise standards.

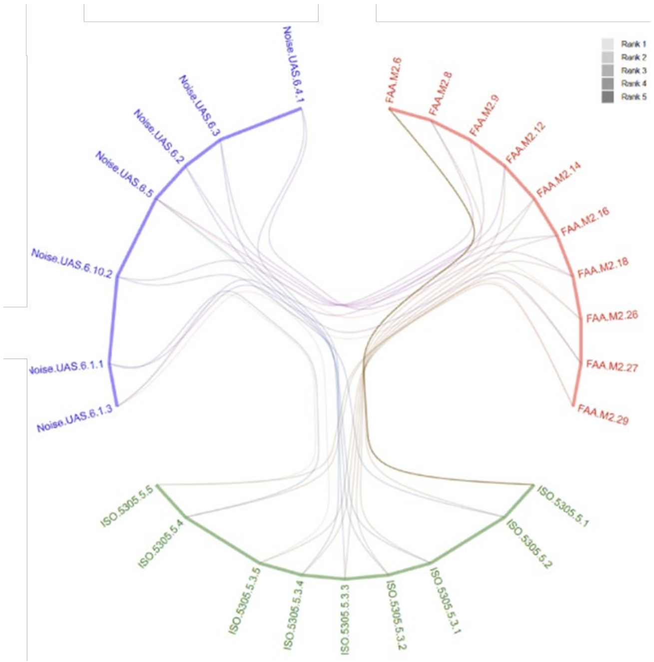

Figure 7. Relationship diagram showing the associations between the existing standards from different entities.

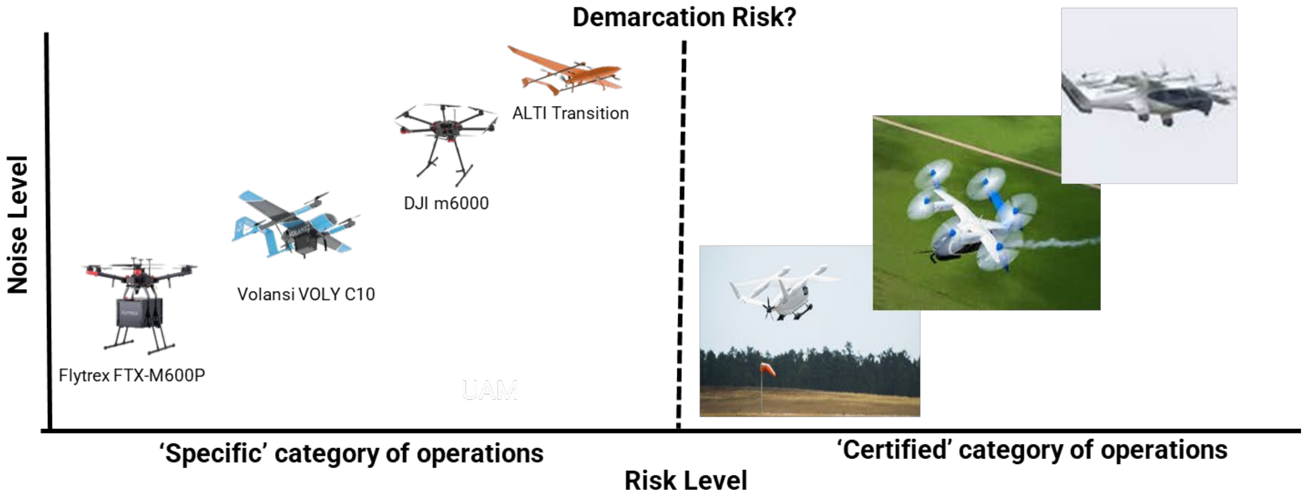

Figure 8. Demarcation between UAS and UAM noise standards.

To investigate the demarcation between the UAS and UAM noise standards, a case study considering the EASA's UAS and UAM noise standards was formulated by our team. By comparing the EASA's UAS Noise Measurement Guidelines and Environmental Protection Technical Specifications (EPTS) for vertical takeoff and landing (VTOL) capable aircraft as shown in Table 1. It is evident that weight cannot be considered as the demarcation parameter since the weight range of both frameworks overlap. Instead, the EASA uses "Risk" as a demarcation parameter between the UAS and UAM noise standards. In general, the EASA defines risk as the potential harm based on the environment, vehicle type, and nature of the operation (EASA, 2023). Higher risk operations require stricter regulations and certifications to ensure safety. Based on this definition, the EASA also provides three categories of risk:

1. Open (Low Risk): Drones are operated in visual line-of-sight under specific limits (e.g., weight, height), typically over nonpopulated areas, with no need for prior authorization (EASA, 2024a)
2. Specific (Low to Medium Risk): Requires an authorization due to higher risks (e.g., flying near people or complex environments) and needs an operational risk assessment (EASA, 2019)
3. Certified (High Risk): For the most dangerous operations (e.g., over urban areas or transporting people) where certification of both the drone and operator is mandatory (EASA, 2024b)

This delineation leads to trying to determine the influence of risk classification on the applicable noise standards. To this end, understanding the risk of annoyance to communities where UAS/UAM vehicles operate in terms of factors such as weight, configuration and concept of operations (CONOPS) is crucial to quantify risk, and thus produces a risk classification that can be mapped to applicable noise standards (i.e., noise metrics, test types, the number of microphones, etc.). The goal of this procedure is to propose proportional applicable noise standards corresponding to certain risk levels. Determining the proportionality of noise standards to the vehicle risk classification requires the evaluation of the Economic Viability (Economic Burden) of alternative noise standards in terms of time, cost, and process complexity.

One of the benefits of the outcome of Task 1.1 is that team members quickly became more knowledgeable of basics on noise standards in preparation for Task 1.2 (breakdown of standards) and were able to build a comprehensive MBSE representation (in SysML) of the current framework (see Task 3.1).

Task 1.2 Breakdown the Noise Standards into Logical Elements

Once a comprehensive database of existing noise standards has been established, the second step is to analyze existing standards to supplement a text-based definition of a standard. This is done by identifying the categories of information necessary to sufficiently define a standard and then use it to compare the existing standards. Our team aimed to demonstrate the flow of procedures, associations, and dependencies across the standard framework items. This was achieved by establishing a clear breakdown of noise standards in a proper structural arrangement as shown in Figure 9. This breakdown was inspired by the works of Bendarkar et al. (2023) and Fazal et al. (2022). Bendarkar et al. (2023)

provided a structural hierarchy of FAA regulations comprising four layers, (1) part, (2) subpart, (3) grouping, and (4) paragraph. Whereas Fazal et al. (2022) constructed a regulatory framework identifying three main categories of regulatory statements, (1) regulation requirement, (2) regulation context, and (3) regulation test.

Table 1. Comparison between the European Union Aviation Safety Agency (EASA) UAS Noise Measurement Guidelines and Environmental Protection Technical Specifications (EPTS) for VTOL capable aircraft (VCA).

	EASA EPTS applicable to VCA	EASA guidance for the UAS between 25-600kg
Weight Range	< 80,000 kg	25 kg – 600 kg
Prescribed Tests	Takeoff (TF), Approach (AP), Level Flyover (LF), Hover (H)	Level Flyover (LF), Hover (H)
Noise Metrics	EPNL (TF, AP, LF), L_AEQ (H)	SEL (LF), L_AEQ (H)
# of Microphones	3 (TF, AP, LF, H*), 9 (H) Inverted Ground Microphones	1 (LF, H) Inverted Ground Microphone
Noise Limits	87.0314 + 9.9673 log10 M (TF) 85.0314 + 9.9673 log10 M (LF) 90.0314 + 9.9673 log10 M (AP) in EPNdB	Not Applicable
# of runs	6 runs (TF, AP, LF, H)	6 runs (LF, H)

Breaking down standards into logical elements facilitates systematic comparison and helps to identify essential information needed to establish standards and ensure traceability. The breakdown in Figure 9 organizes standards into sections, paragraphs, and equations, ensuring clear and systematic representation. It also ensures uniformity, enabling diverse standards to seamlessly fit into a consistent framework. A breakdown was created for each of the noise standards gathered in the database.

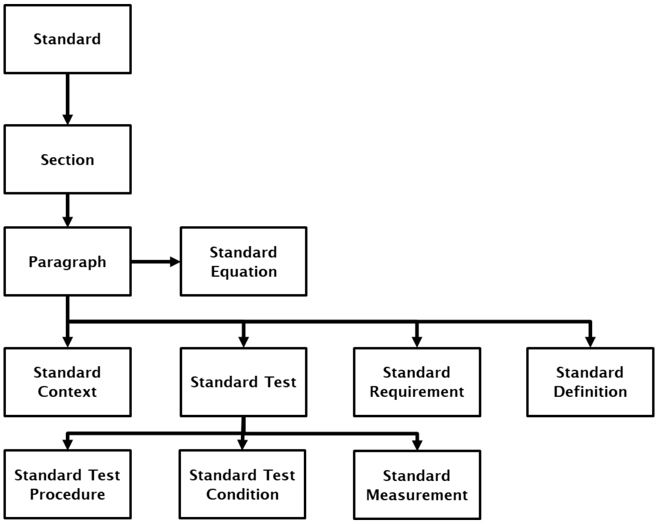

Figure 9. Standards breakdown and elements.

Establishing a breakdown of noise standards is a crucial first step in creating a model-based standards setting framework. As mentioned previously, one of the aims of the model is to provide a traceable and manageable model-based environment to keep track of relationships and dependencies between all the standards. In addition, the complexity of this process becomes apparent by examining the intricate networks created between standard framework items. The MBSE model can aid in nullifying this complexity by capturing the process of creating the certification plan in addition to other supplementary domain knowledge within one model that is the singular source of truth. More information about the MBSE model's representation of the framework that was created in MagicDraw® is provided in Task 3.1.

A critical element of the standard breakdown is the standard requirement. Defining and maintaining a good set of requirements is vital for the successful design, development, and operation of systems, products, and processes. A requirement is defined as "a statement that identifies a system, product or process' characteristic or constraint, which is unambiguous, can be verified, and is deemed necessary for stakeholder acceptability" (International Council on Systems Engineering, 2006). "Good" requirements are those having attributes such as necessary, unique, unambiguous, clear, concise, complete, consistent, technically feasible/achievable/obtainable, traceable, measurable/quantifiable, verifiable (e.g., testable), able to be validated, operationally effective, and survivable and singular as outlined by the U.S. Department of Defense (DoD) *Systems Engineering Guidebook* (2022). In addition, requirements can vary in their type, which encompasses functional, nonfunctional, design, performance, certification, etc. (Firesmith, 2005).

The FAA Writing Standards provide a useful guide for defining the requirements to satisfy the desirable requirement attributes outlined by the DoD *Systems Engineering Guidebook* (2022) that are nonfunctional in nature (detailed in the Task 1.3). These standards include word choice such as using "must" instead of "shall," using short sentences and short paragraphs, limiting the use of abbreviations and acronyms, etc. (FAA, 2003). While converting the standards into requirements, the following considerations were taken (Kim et al., 2023):

- Not all standards needed to be converted into requirements.
- A single standard often needed to be broken down into multiple requirements. Conversely, multiple standards were sometimes merged into a single requirement.
- The standards do not always provide all the necessary information, so additional metrics and clarifying information were gathered from literature reviews and other noise standards related documents.

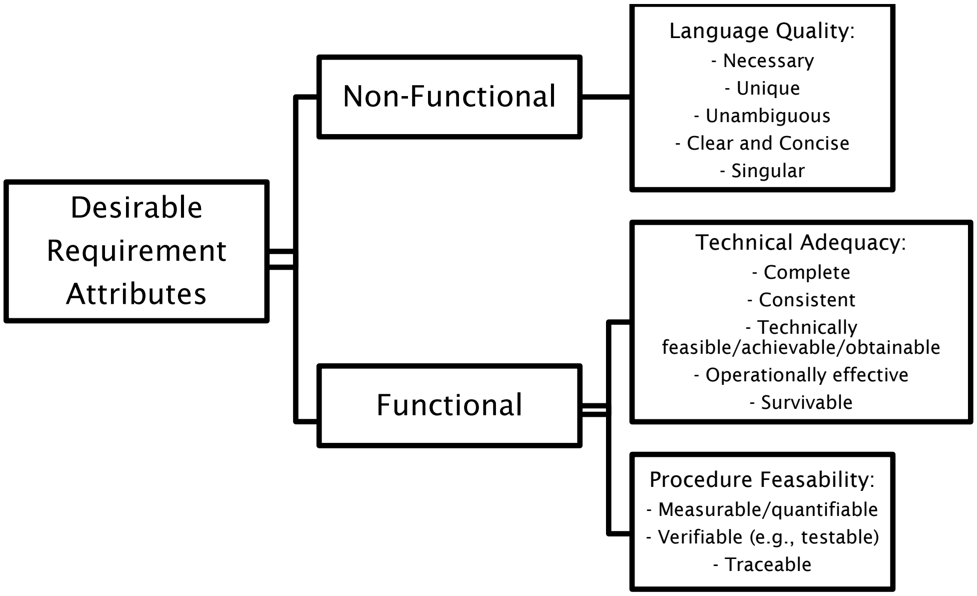

Figure 10. Attributes of desirable requirements.

Task 1.3 Define a validation process for noise standards.

Following the creation of a standards database and the breakdown of standards into their elements, it is imperative to verify noise standard requirements satisfy the desirable requirement attributes. The attributes can be classified into functional and nonfunctional categories, as illustrated in Figure 10. Functional attributes are concerned with the feasibility and technical adequacy of the requirements, whereas nonfunctional attributes are those concerned with language quality. Functional attributes require data for verification, unlike nonfunctional attributes. To this end, the standards requirements

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analysis process (outlined in Figure 11) provides a framework that allows for the verification of regulatory requirements' adherence to the desired requirement attributes. The outline indicates that once the requirements are defined, data need to be collected using flight testing data. Raw data are then processed by applying procedures such as correlating noise measurement data with position, calculating the required noise metrics (e.g., sound exposure level [SEL]), and applying the necessary data corrections (duration adjustments). The processed data are then used to verify the requirements. Additionally, the requirements can also be checked for functional attributes in the presence of available test data and experience. This is an iterative process, so there is a feedback element that allows for the refinement of the requirements such that it will satisfy the desired requirement features.

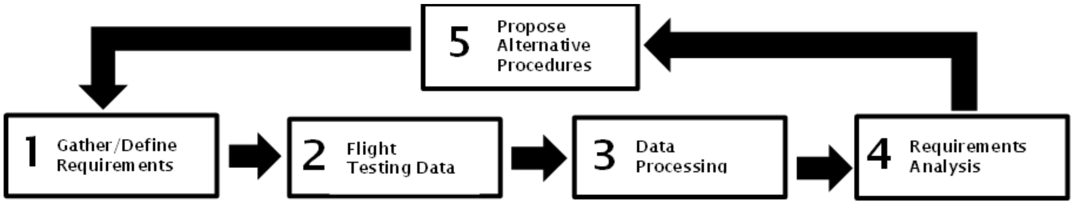

Figure 11. Noise standards requirements analysis process.

The iterative nature of the requirements analysis process dictates whether a standard requirement is deemed unsatisfactory or can be improved in terms of functional attributes; alternative standard requirements need to be proposed (as shown in Figure 11). These alternative requirements are meant to bridge the current gap that exists between current noise standards and UAS/UAM certification needs. Proposing alternative requirements will contribute to capturing the uniqueness of UAS/UAM vehicles while also addressing the challenges associated with their certification (i.e., operational and noise metric limitations). The proposed standards may include the use of different noise metrics, microphone setups, or additional flight tests that better capture the specific mission profile of UASs. Such suggestions could convert to opportunities for potential process streamlining if recommended practices are uncoordinated with current procedures.

The alternative standard requirements can be generated by identifying combinations in the morphological matrix shown in Table 2. The options provided by the matrix are surveyed from literature including FAA, EASA, and ISO noise standards.

Table 2. Noise standards morphological matrix.

Flight Test Profile	Flyover	Hover	Vertical Takeoff/Landing	Infrastructure Inspection	Maneuver
Microphone Type	Ground microphone	Inverted ground microphone	Elevated microphone on a tripod	Elevated microphone on a crane (high altitude)	-
Microphone Array Design	Linear (horizontal)	Circular	Vertical, elevated microphone array	-	-
Noise Measurement Metric	Sound exposure level (SEL)	A-Weighted maximum sound level (LAMAX)	Equivalent sound level (LAEQ)	Effective perceived noise level (EPNL)	-

The objective for generating alternative noise standards is to explore options for formulating a streamlined noise certification process. The following target objectives for streamlining the certification process are currently under consideration:

- Reduce the number of steps in the process, with anticipated savings in time and cost.
- Replace steps in analysis, data preparation, and post-processing with digital tools.
- Enhance automation on procedural tasks (e.g., data retrieval, queries, processing, and report generation).
- Simplify setup requirements to facilitate more test locations/weather windows.

In general, the process of assessing the alternative noise standards can be approached by conducting a series of tradeoff studies between alternative noise standards' technical feasibility and economic viability to find the best alternative in the design space illustrated in Figure 12. Technical feasibility or standard effectiveness can be interpreted as the standard's ability to capture UAS/UAM noise sources and their impact on communities. On the other hand, economic viability, also referred to as economic burden, evaluates the alternative standard time, cost, and complexity.

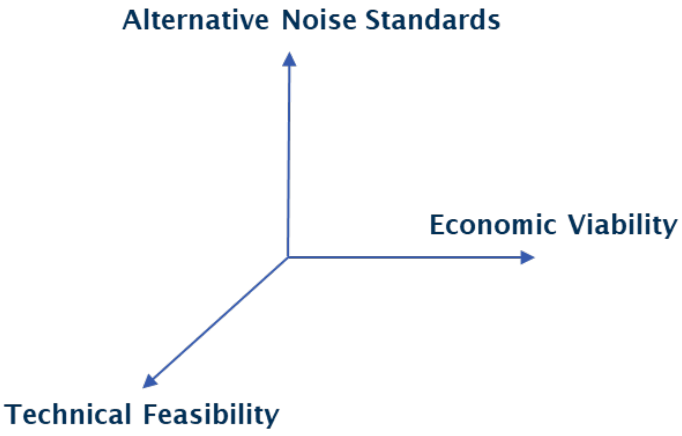

Figure 12. Alternative noise standards tradeoff space.

Along with the selection of the alternative noise standards of interest, the outcome of this exercise is to present certain use cases for which a feasibility demonstration of an equivalent procedure would be possible. This effort would require data for calibrating the standard-setting model against various UAS and UAM vehicle configurations. Additionally, this effort would require data to showcase quantifiable improvements against the process criteria listed above, while meeting the same noise standards constraints and requirements as the benchmarked certification procedure. The quantitative assessment, which will be supported under the PIM module developed under Task 4, is the main enabler for allowing an iterative process until process alternatives can meet the expectations for process streamlining and simplification.

As mentioned above, the existing connections and synergies with other ASCENT projects are expected to provide the resources needed to support the demonstration of this framework as a platform for evaluating equivalent procedures.

Milestones

Between October 2024 and September 2025, the following milestones were achieved:

- Completed the exploration and assessment of NPRM (86 FR 48281) (FAA, 2022), which presents only the noise certification basis for one new model of UAS seeking type certification, the Matternet® M2.
- Reviewed the recently approved remotely piloted aircraft (RPA) for noise certification of small UAS category vehicles.

Major Accomplishments

- Performed a literature search and documented regulations and current testing standards for small UAS.
- Defined a traceable structure for UAS noise certification requirements, using the MBSE verification model developed for the transport category.
- Published articles with AIAA SciTech 2025.

Publications

Published Conference Proceedings

Ali, H. E., Ravikanti, B., Balchanos, M. G., Harrison, E., & Mavris, D. (2025). MBSE Enabled Requirement Verification for a Traceable Regulatory Analysis Framework of UAS Noise Certification Standards. *AIAA SCITECH 2025 Forum* (p. 0367).

Mali, H., Geneti, N. F., Balchanos, M. G., Harrison, E., & Mavris, D. (2025). A Process Evaluation and Visualization Framework for Unmanned Aerial System (UAS) Noise Certification Testing. *AIAA SCITECH 2025 Forum* (p. 0368).

Balchanos, M., Ravikanti, B., Ali, H., Mali, H., D Harrison, E., & N Mavris, D. (2024, September 9-11). *A Regulatory Analysis and Process Improvement Decision Support Framework for Unmanned Aerial System (UAS) Noise Certification* [Conference presentation]. Quiet Drones 2024 Symposium, Manchester, United Kingdom.

Written Reports

Balchanos, M., Mavris, D. (2025). (Period ending December 2024) *ASCENT Quarterly Report, ASCENT Project 061 - Noise Certification Streamlining*. Award number 13-C-AJFE-GIT-066.

Balchanos, M., Mavris, D. (2025). (Period ending March 2025) *ASCENT Quarterly Report, ASCENT Project 061 - Noise Certification Streamlining*. Award number 13-C-AJFE-GIT-066.

Balchanos, M., Mavris, D. (2025). (Period ending June 2025) *ASCENT Quarterly Report, ASCENT Project 061 - Noise Certification Streamlining*. Award number 13-C-AJFE-GIT-066.

Balchanos, M., Mavris, D. (2025). (Period ending September 2025) *ASCENT Quarterly Report, ASCENT Project 061 - Noise Certification Streamlining*. Award number 13-C-AJFE-GIT-066.

Balchanos, M., Mavris, D. (2024). *Annual Report (period ending September 2024), ASCENT Project 061 - Noise Certification Streamlining*. Award number 13-C-AJFE-GIT-066.

Outreach Efforts

- Completed follow-up meetings with OEM partners for feedback on the certification model.
- Presented the model-based framework in two webinars.
- Completed a project overview and capability demonstration to the Volpe National Transportation Systems Center (Volpe) and requested information for model finetuning.
- Participated in conferences (2025 AIAA SciTech Forum and Quiet Drones 2024 Symposium).
- Participated in the FAA NEAT Series with an overview of ASCENT Project 061.
- Participated in the Spring 2025 ASCENT Meeting, where the team presented the latest research findings and final recommendations for standard setting.
- Interacted with the leadership of the ASTM F38 Committee and provided an overview of the A61 framework capabilities, per their request for collaboration with the ASCENT Project 061 team.

Awards

None.

Student Involvement

All participating graduate students have supported Task 1 activities by contributing to the literature, conducting ground research, and reviewing current regulations and FAA-instructed certification procedures. Recent efforts to document current regulations for UAS noise certification are currently led by Balaji Ravikanti.

Plans for Next Period

- Project ended on September 30, 2025.
- Publish peer-reviewed journal articles with *AIAA Journal* and AIAA SciTech.

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Task 2 - Develop a Library of UAS and Testing Procedures

Georgia Institute of Technology

Objectives

Task 2: Develop a library of UAS and testing procedures

- 2.1 Complete technical documentation of UAS configurations
- 2.2 Complete technical documentation of UAS noise testing equipment
- 2.3 Define UAS noise test plans
- 2.4 Define possible simulation techniques

Research Approach

Task 2.1 Complete Technical Documentation of UAS Configurations

Research tasks on investigating and archiving technical documentation of UAS configurations, as well as recommended procedures for noise testing, started in July 2022. Due to the lack of historical data about the noise generated by most UAS models, the FAA is unable to provide generally applicable noise standards for UAS (FAA, 2021). This insufficiency in data is caused primarily by the novelty and variety of UAS, such that no clear categorization of the systems is currently established. Figure 13 illustrates this problem by listing some of the different UAS configurations currently available.

The aforementioned problem is exacerbated by the various mission profiles of UAS systems and their different operating environments (Kim, 2022). As an alternative measure, the FAA issues Rules of Particular Applicability (RPA) for applicants who wish to certify their product for noise (FAA, 2023). To achieve this, the FAA assumes that the fundamental physics of UAS operation and noise are scalable if UAS shares comparable characteristics with crewed aircraft. As a result, the current noise standards for crewed aircraft outlined in 14 CFR § 36 (2025) can be applied to UAS or extrapolated for testing lower-weight UAS at lower altitudes. An example of this is the "Noise Certification Standards: Matternet Model M2 Aircraft" (FAA, 2021), which is the first RPA establishing a noise certification basis for a single model of aircraft described only for the Matternet® Model M2 (FAA, 2021). These RPAs alongside the Volpe UAS Testing Campaign's noise measurement reports have been valuable for documenting testing procedures and in identifying the most important technical challenges for UAS noise testing.

So far, depending on the availability of data, only multirotor UAS were encompassed within the scope of the provided analysis. This includes vehicles such as the Matternet Model M2, Tarot® X8, and Flytrex® FTX M600P. The three UASs are depicted in Figure 13. The Matternet Model M2 was issued the first RPA by the FAA in 2022; therefore, it was used for benchmarking efforts early in the pivot toward UAS from the transport category. Tarot X8 is employed by the ASCENT Project 077 team for their noise measurement testing campaigns. Thus, in collaboration with ASCENT Project 077, a

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dataset was obtained from the testing campaign and was used to investigate the noise generated by Tarot X8 within the scope of the benchmarked regulations. Finally, the Flytrex FTX M600P is the system under test (SUT) for the most recent case study under this project. Its noise certification standards were issued on July 3, 2023, and upon collaboration with the ASCENT Project 094 team, a dataset was obtained from the Causey Noise Measurement Testing Campaign that facilitated this case study. More details about the case study are provided in Task 4.

(a) Matternet® M2 (b) Tarot X8 (c) Flytrex® FTX M600P

Figure 13. Unmanned aerial systems (UAS) analyzed within this project.

Task 2.2 Complete Technical Documentation of UAS Noise Testing Equipment

Part of the motivation behind looking at RPAs and Volpe UAS noise measurement campaigns' reports, as well as collaborating with the ASCENT Project 077 team, is to generate technical documentation on UAS noise testing equipment. The equipment employed within a testing procedure includes everything from pressure sensors (i.e., microphones), to data recorders, weather data microstations, aircraft tracking systems, etc. This equipment will be supported by data measurement and collection software.

Microphones are the most critical element in noise testing. Figure 14 showcases three types of microphones that can be utilized during noise testing: (1) ground microphones, (2) inverted ground microphones, and (3) elevated microphones. Ground microphones, including the inverted ones, tend to minimize interference with directed or reflected sound, and reduce measurement uncertainty related to the microphone elevation; however, ground microphones tend to be more complex to set up and more costly than the elevated microphones. In contrast, elevated microphones are simpler to set up and less expensive, but elevated microphones suffer from interference with directed and reflected sound. All microphones utilized for noise measurement are outfitted with windscreens to ensure reliable acoustic measurements while minimizing noise due to weather variations (e.g., rain and wind) and birds.

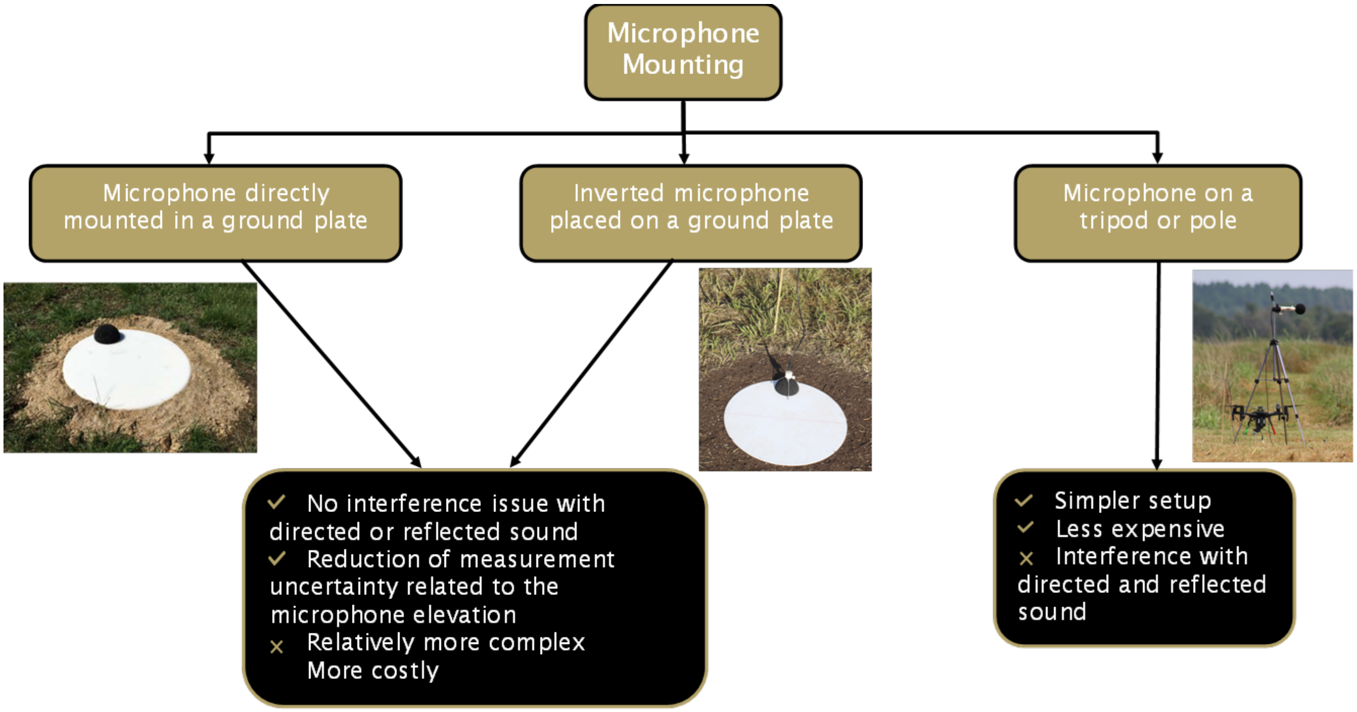

Figure 14. Microphone types and corresponding advantages and disadvantages.

The pressure fluctuations captured by the microphones are digitized via a data recorder. Data recorders are also used to power microphones and control the timing, synchronization, and data transfer between the input module and external host such as a computer. Moreover, meteorological conditions are continuously monitored during acoustic measurements. Weather data logging can be collected via weather microstations connected to anemometers and temperature/humidity sensors, as shown in Figure 15.

Figure 15. Anemometers for weather data acquisition equipment.

Time-space-position information for UASs within a noise testing procedure is captured by aircraft tracking systems such as the Survey and Tracking Apparatus for Research in Transportation (START) depicted in Figure 16. START is a tracking system developed by Volpe "for the purpose of deriving precise positioning and timing information from UAS and other automated platforms" (James et al., 2021).

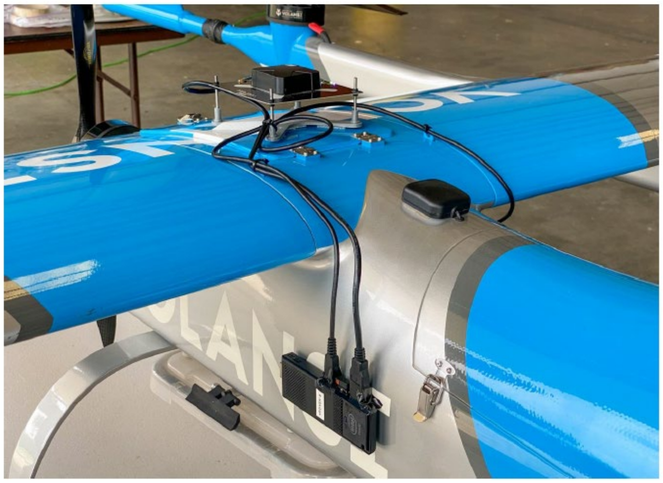

Figure 16. Survey and Tracking Apparatus for Research in Transportation (START) aircraft tracking system.

Task 2.3 Define UAS Noise Test Plans

Research tasks on investigating and archiving technical documentation of UASs, as well as recommended procedures for noise testing, started in July 2022. One of the key studies that the ASCENT Project 061 team has started to document, which has been valuable in identifying the most important technical challenges for UAS noise testing, is the document titled "Noise Measurement Report: Unconventional Aircraft" by the Choctaw Nation of Oklahoma (July 2019). The practice described for UAS noise testing took place on a grassland, which, taking the flight envelope into consideration, is not suitable due to the following reasons:

- Dense areas can have a different "perceived" noise.
- High altitudes and dense areas over buildings and hard surfaces can have different reflective behaviors.
- Within buildings, noise can be reflected, amplified, or attenuated.

Part of this grassroots effort in discovering the state of the art is the technical documentation on UAS noise testing equipment. By assessing testing procedures from a regulatory perspective, we can build some simple alternatives under the system verification model (Figure 17 shows examples). Finally, the UAS noise test plans must be defined and executed. Physical testing will not cease to exist, but simulation techniques are needed for testing process alternatives.

A major part of the study for this cycle involved gathering available experimental test data to aid in understanding both the sensitivity of noise metrics to flight test parameters or test setup parameters and the times and costs associated with various sub-steps of a noise testing procedure. Note that the experimental noise testing campaign is more rigorous in many ways compared with the certification noise testing procedures. This enabled us to compare various microphone locations, flight conditions, and metrics, which is not possible when limited to the data typically available from certification-type noise testing procedures.

The experimental test campaign whose data was extensively utilized in this cycle of the study was the Causey test campaign. The objective of the testing campaign was "to gather data on UAS noise emissions in compliance with the UAS noise regulations specified in 14 CFR § 135." Unlike other test campaigns, which may not be compliant with certification norms, the Causey campaign is explicitly meant to gather certification quality data. The report provides the acoustic measurements and resultant dataset. FAA, Volpe, and Blue Ridge Research and Consulting (BRRC) were the parties involved. Chris Hobbs (FAA) headed UAS flight operations, Robert Samiljan (Volpe) coordinated the vehicle tracking data collection, and Michael James (BRRC) managed the acoustic data collection.

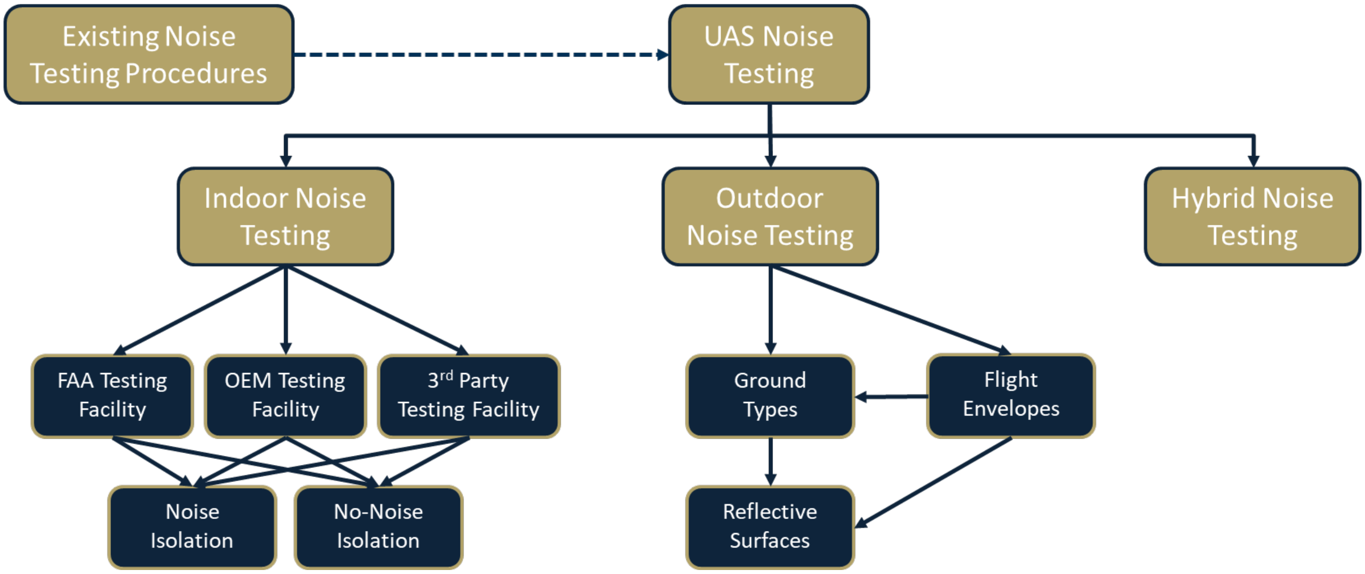

Figure 17. Alternative noise testing procedures for an unmanned aerial system (UAS). OEM: original equipment manufacturer.

Table 3 lists the empty and maximum weights of the test vehicles shown in Figure 18. Vehicles performed flyover and hover operations for multiple flight conditions. The weight of the Flytrex FTX-M600P is comparable to the Matternet M2 (for which there is an existing recent noise regulation linked in references), which has a MTOW of 29 lb, including a 4-lb payload. However, it is worth noting that the Flytrex FTX M600P is a hexacopter, whereas the Matternet M2 is a quadcopter. An RPA for the noise certification of Flytrex FTX-M600P was approved recently, alongside six other vehicles of the same class. Flight conditions are derived based on various combinations of weight, speed, and altitude. Three groups of “test points” were conducted (namely, level flyover operations; hover operations; and idle, takeoff, landing, or operational level flyover operations). The campaign took place from July 26 to July 29, 2021. Each day, a different vehicle underwent testing.

Table 3. Causey test campaign vehicle weights.

Weight	Flytrex FTX-M600P	Volansi® VOLY C10	DJI® m210
Empty (lb)	26.8	51.4	11.8
Max (lb)	33.4	55.0	-

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Figure 18. Test vehicles for Causey testing campaign.
From left to right, Flytrex FTX-M600P, Volansi VOLY C10 and DJI® m210.

An additional day of Flytrex FTX-M600P measurements was conducted to capture new test points and repeat two flyover test points to account for day-to-day variations. The goal was to complete six repeated test flights of each condition; however, some test points were repeated more than six times, as will be discussed in later sections.

Figure 19 illustrates the Causey testing campaign layout. This view is later used in the visualization environment that is to host all the key details of a test procedure to enable effective decision-making.

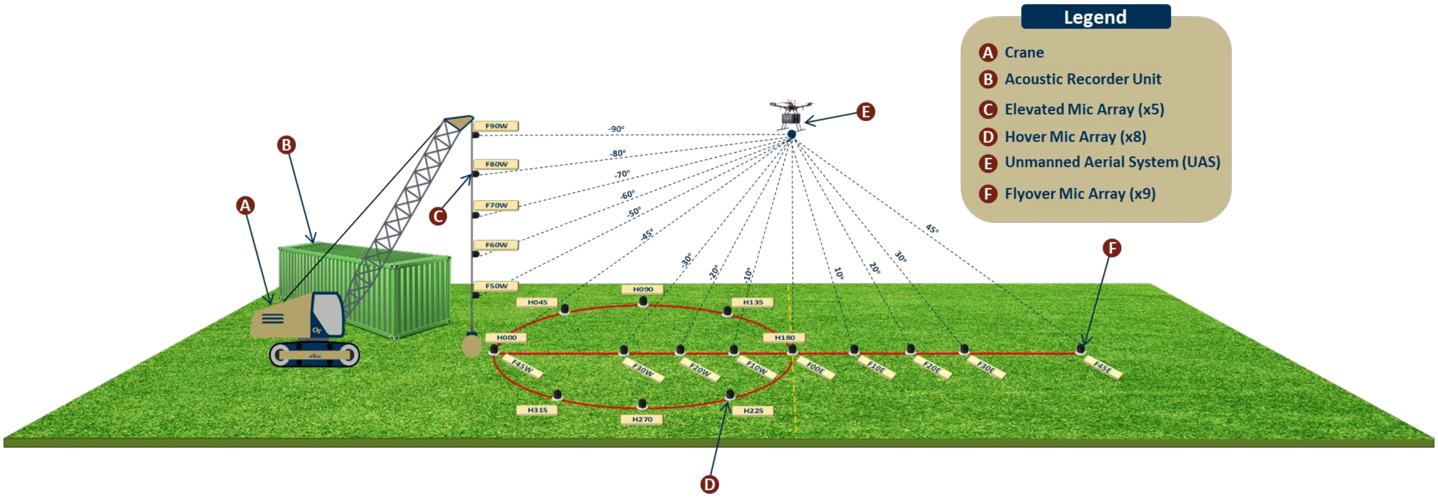

Figure 19. Causey test campaign concept of operations.

Task 2.4 Define Possible Simulation Techniques

Within the scope of this project, the MBSE model was used to assess current noise certification procedures. Typically, MBSE methods are used to represent a vehicle's lifecycle and enable the use of data and information as an integrated systems engineering approach. In the case of ASCENT Project 061, the product is a process architecture, within which current procedures will be assessed and equivalent procedures will be proposed, defined, implemented, and tested within this environment. The full MBSE model formulation for certification and implementation is shown in Figure 20.

The validation process contains the steps needed to demonstrate that vehicle noise levels calculated from flight testing results are meeting requirements. Part of meeting the requirements is the instrumentation setup, which is implemented as a logical architecture within the model. A library of instrument model representations is also constructed, from which

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alternative instrumentation lineups can be modeled. The latter feature is key, as this framework should allow for the evaluation of equivalent procedures (e.g., ground microphone placement). Other components of the verification model are the test procedures and the test report checklist, which are prototyped as activity diagrams in SysML, as well as the vehicle configurations represented as a state machine.

Completing the verification model is any applicable regulation text in the form of a SysML verification thread. With the verification model in place, the user can import any UAS model, perform the certification equivalent process by executing the verification model, and then generate a final report which would contain the instrument validation document and flight test plan. It is crucial that the overall framework be implemented in a highly modular fashion to obtain the needed flexibility for testing equivalent procedure alternatives and to accommodate a broader range of air vehicle designs and configurations. The SysML implementation currently comprises the following modules:

1. Requirement translation and constraints
2. Noise testing instrument architecture
3. Procedures, protocols, and behavior
4. SUT
5. System verification model overview
6. Auto-report generation and output to process evaluation model

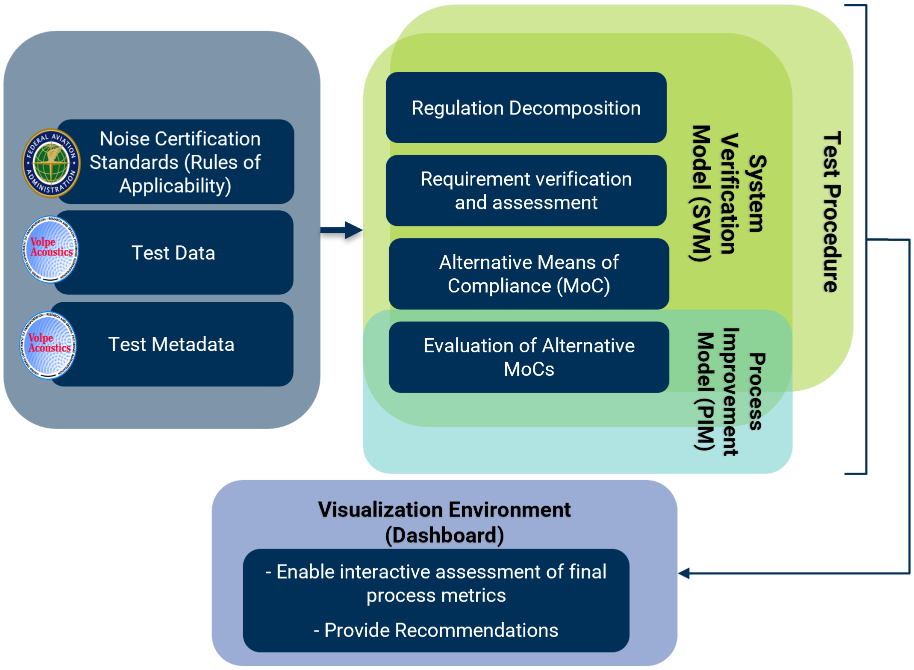

Figure 20. Model-based systems engineering (MBSE) verification model structure.

Event Process Modeling

With detailed guidance from the documents listed above, event-driven processes were defined and created within the certification model. Additions include modeling of the test-day acoustic collection process and test scenario event processes (i.e., flyover, hover).

Library Creation

A new task was identified to command the creation of libraries within the certification model, to allow for added flexibility and modularity. Current libraries include the aircraft library, microphone library, and data amplifier library. The SUT representation has been modified to allow for adaptability to various UAS types and configurations.

Aircraft Testing Environment
Another finalized improvement on the certification model is the modeling of the UAS test environment, including the flight test setup configuration. With input from documents such as RPAs and Volpe UAS noise measurement campaign reports, the model was updated and refined to include various instrumentation system architectures.

Noise Calculation
UAS noise certification only requires a flyover test, but noise certification also specifies a supplemental hover test to augment the process of collecting noise data that will inform the generation of generally applicable noise standards for UAS. The hover test, as described by the FAA in the noise certification standards for the Matternet M2, is a voluntary test that “will not be used to inform the applicant’s airworthiness or type certification basis or be evaluated against any noise limits or regulatory criteria for noise certification purposes” (FAA, 2021). So far, UAS RPAs have described two noise metrics for noise measurements: (1) SEL for the flyover test and (2) equivalent sound level (L_{eq}) for the hover test (FAA, 2021).

1. **Sound Exposure Level:**
   SEL is an energy-averaged A-weighted sound level over a specified period of time or single event, with a reference duration of 1 s. SEL can be calculated using two methods, defined as follows (Bennett & Pearsons, 1981):

   1.1- Continuous time integration:

   $$L_{AE} = 10\log_{10}\left[\frac{\int_{t_1}^{t_2} 10^{\frac{L_A(t)}{10}}dt}{1\,sec}\right] \qquad \text{(Eq. 1)}$$

   where t_1 and t_2 define the time interval, and $L_A(t)$ is the time function of A-weighted sound level during the time for $t_1 - t_2$.

   1.2- Temporal sampling:

   $$L_{AE} = 10\log_{10}\left[\sum_{i=1}^{n} 10^{\frac{L_A(i)}{10}}\Delta t\right] \qquad \text{(Eq. 2)}$$

   where $L_A(t)$ is the instantaneous A-weighted sound level for the n^{th} sample, n is the number of samples taken during the observational period, and Δt is the time interval between samples.

   As mentioned previously, UAS RPAs prescribe the use of SEL for the flyover test, in which they specify that the integration time $t_2 - t_1$ in practice must not be less than the time interval during which $L_A(t)$ first rises to within 10 dB(A) of its maximum value (L_{Amax}) and last falls below 10 dB(A) of its maximum value. In addition, the regulations allow for the use of an integrating sound level meter to obtain L_{AE} directly rather than manually calculating L_{AE} (FAA, 2021).

2. **Equivalent Sound Level:**
   L_{eq} is the level of the A-weighted sound energy averaged over a specified period of time. Similar to L_{AE}, it can be calculated by two methods, defined as follows (Bennett & Pearsons, 1981):

   2.1- Continuous time integration:

   $$L_{eq} = 10\log_{10}\left[\frac{\int_{t_1}^{t_2} 10^{\frac{L_A(t)}{10}}dt}{t_2 - t_1}\right] \qquad \text{(Eq. 3)}$$

   where t_1 and t_2 define the time interval, and $L_A(t)$ is the instantaneous A-weighted sound level.

   2.2-Temporal sampling:

   $$L_{eq} = 10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} 10^{\frac{L_A(i)}{10}}\right] \qquad \text{(Eq. 4)}$$

where $L_A(t)$ is the instantaneous A-weighted sound level for the n^{th} sample and n is the number of samples taken.

UAS RPAs prescribe the use of L_{eq} for hover tests only. Similar to L_{AE}, the regulations allow for the use of an integrating sound level meter to obtain L_{eq} directly rather than calculating it manually (FAA, 2021).

Before L_{AE} and L_{eq} are calculated, corrections must be applied to the measured data to account for uncertainties related to the measurement system, microphone and recording system used, background noise, actual flight path, and meteorological conditions present when the measurements were taken.

The use case described in Task 4 utilizes a Python® code to parse through the sound pressure time-history (audio) signals obtained from the Flytrex FTX M600P flyover and hover tests during the Causey UAS Acoustic Measurements campaign and calculate both L_{AE} and L_{eq} based on the equations above. Regarding the implementation of noise metric calculations, there is no option for directly performing such analyses within the SysML-based certification model. A possible solution is to create a function in Matlab® and then incorporate the analysis in the verification thread.

Milestones

- Reviewed UAS testing procedures from the literature.
- Obtained useful test data from collaborators.
- Established connections with OEMs and other research teams for further investigations.

Major Accomplishments

- Created scripts that are required to generate multiple noise metrics from raw frequency domain data.
- Documented UAS noise testing practices and processes.

Publications

Published Conference Proceedings

Ali, H. E., Ravikanti, B., Balchanos, M. G., Harrison, E., & Mavris, D. (2025). MBSE Enabled Requirement Verification for a Traceable Regulatory Analysis Framework of UAS Noise Certification Standards. *AIAA SCITECH 2025 Forum* (p. 0367).

Mali, H., Geneti, N. F., Balchanos, M. G., Harrison, E., & Mavris, D. (2025). A Process Evaluation and Visualization Framework for Unmanned Aerial System (UAS) Noise Certification Testing. *AIAA SCITECH 2025 Forum* (p. 0368).

Balchanos, M., Ravikanti, B., Ali, H., Mali, H., D Harrison, E., & N Mavris, D. (2024, September 9-11). *A Regulatory Analysis and Process Improvement Decision Support Framework for Unmanned Aerial System (UAS) Noise Certification* [Conference presentation]. Quiet Drones 2024 Symposium, Manchester, United Kingdom.

Outreach Efforts

- Provided full Year 4 performance review to the FAA AEE.
- Facilitated technical discussions and feedback provided by Volpe.
- Collaborated with the ASCENT Project 077, Dr. Eric Greenwood's research group, and Flytrex Aviation LTD.

Awards

None.

Student Involvement

All students participated in the collection and review of UAS noise testing practices and processes. Hussein Ali led the review of available noise testing data and the creation of scripts of noise metrics evaluation.

Plans for Next Period

- Project ended on September 30, 2025.

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® Matlab is a registered trademark of The Mathworks Inc., Natick, Massachusetts.

- Publish peer-reviewed journal articles with *AIAA Journal* and AIAA SciTech.

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Kim, D., Karagoz, F., Datta, S., Balchanos, M., Anvid, D., Harrison, E., & Mavris, D. N. (2022). A Model Based Systems Engineering Approach to Streamlined Noise Certification of Transport-type Aircraft. *33rd Congress of International Council of the Aeronautical Sciences ICAS*, Stockholm, Sweden.

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Task 3 - Develop a Noise Certification Procedure Based on Existing Practices

Georgia Institute of Technology

Objectives

The focus of Task 3 is to develop an overall definition of a more flexible certification process and the evaluation criteria for determining that the procedure is more streamlined than the baseline. The pivot to a UAS focus is well aligned with the objectives of this task, where flexibility will be driven by the requirement for the MBSE model to accommodate a range of UAS configurations and payloads. Task 3 will build upon the capabilities of the integrated MBSE platform and leverage contributions from all other tasks. The following tasks will be conducted under Task 3:

Task 3: Develop a noise certification procedure based on existing practices
    3.1. Transfer noise testing plans to the MBSE model
    3.2. Transfer noise testing data to the MBSE model
    3.3. Develop a full noise test plan
    3.4. Implement a validation process

Research Approach

Tasks 3.1 and 3.2 Transfer Noise Testing Plans and Data to the MBSE Model

Task 3.1 seeks to define what is meant by a “flexible” process. One way to define the “flexible” process is to determine whether the introduction of a different vehicle configuration leads to many incompatibilities with the streamlined process under evaluation. For instance, it is important to assess how the UAS configuration affects the microphone technology and quantity needed and microphone placement in the testing facility. Task 3.1 will involve testing procedures and producing mapping compatibilities between vehicle configurations and testing procedures. A set of criteria and evaluation metrics is needed to assess the combinations of vehicle configuration, testing procedures, and uncertainty factors against regulatory-derived requirements, which will be implemented within the MBSE certification framework. Hence, a proposed set of flexibility criteria for the certification process could include the following considerations:

- Compatibility and applicability of equivalent procedures
    - Alternatives in the testing procedure should be accounted for in the model for verification (i.e., more microphones vs. more flight test points)
- Complexity (e.g., if a switch to another configuration requires more steps to setup) and additional instrumentation if a vehicle is more sensitive to variations in certain factors during testing.

- Sensitivity to weather and other aleatory uncertainties

The defined criteria will be tested and applied in other tasks; hence, this task is considered complete.

A regulation paragraph can contain both quantitative requirements and inspectional requirements. Quantitative requirements refer to those that contain numbers or a range of numbers to be met. Inspectional requirements usually do not contain numbers but ask the test procedure to follow the instructions or guidelines given in the paragraph. In the verification model, such paragraphs cannot be directly adopted but need functional breakdown. For quantifiable requirements, the subjects for which the quantified constraints are designed are identified and separated from each other for the convenience of validation. For an inspectional requirement, a straightforward number is not available to make constraints out of, but a simple ‘yes’ or ‘no’ test can be implemented to address the requirement. With the above modification logic, our team used the function of the requirement diagram in the MBSE model to delineate each requirement within each regulation paragraph. The requirements are constructed with several blocks in addition to the two archetypes mentioned above. Figure 21 shows the formal requirement breakdown process with the help of a requirement from the noise regulations of the Matternet M2. Table 4 above shows the mapping of the broken-down requirements to the test data which enables verification of the requirements.

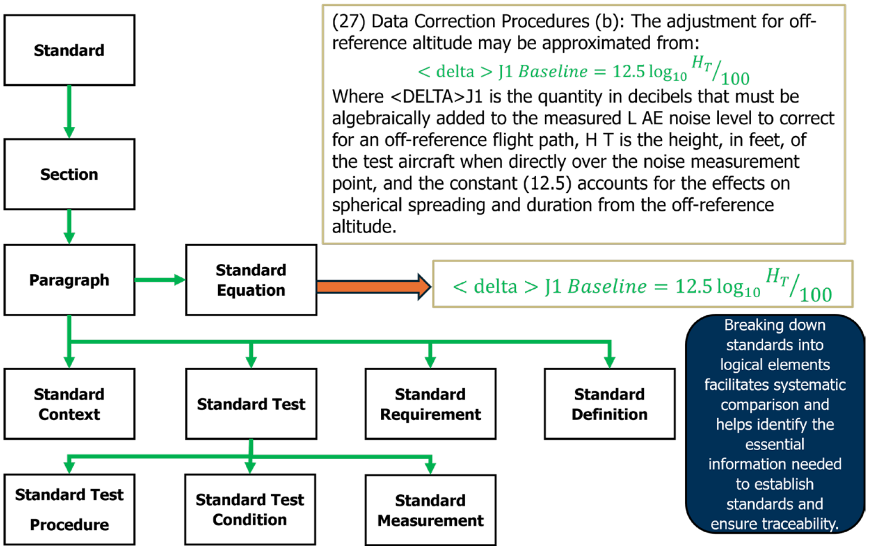
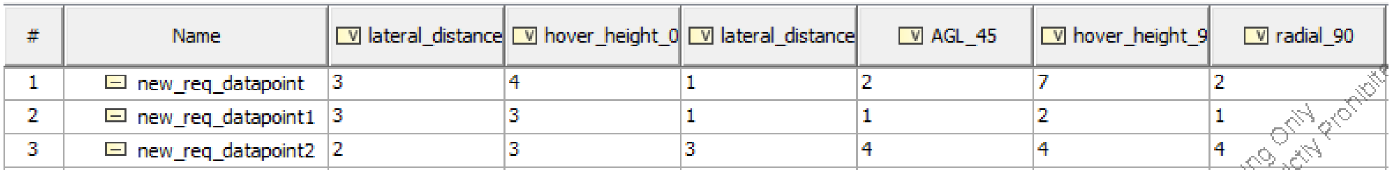


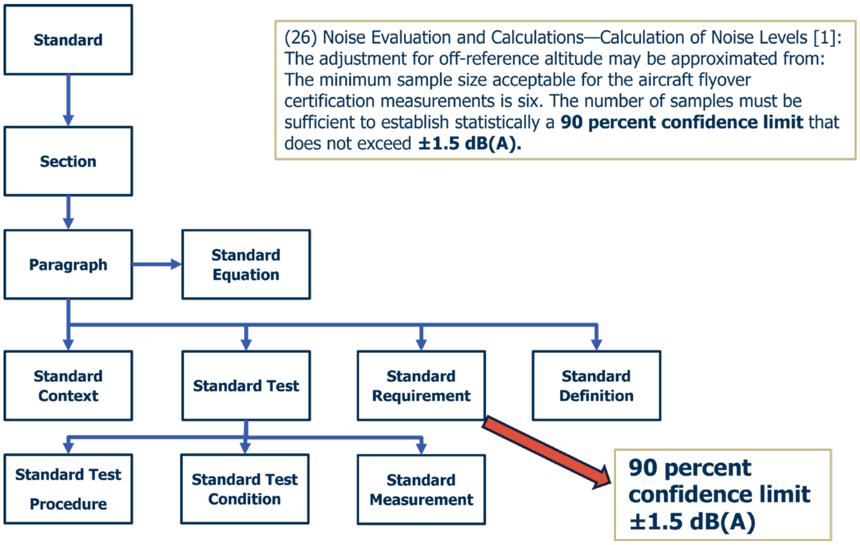
Figure 21. Requirements breakdown highlighting standard equation element.

Table 4. National instance table.



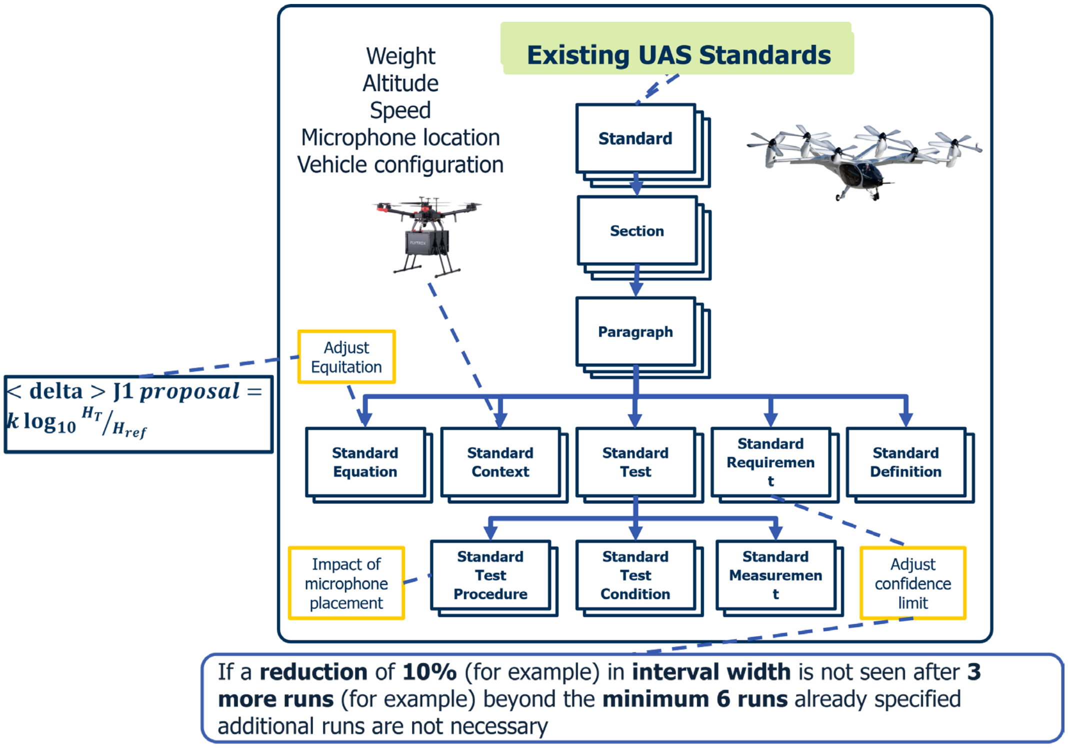
#	Name	lateral_distance	hover_height_0	lateral_distance	AGL_45	hover_height_9	radial_90
1	new_req_datapoint	3	4	1	2	7	2
2	new_req_datapoint1	3	3	1	1	2	1
3	new_req_datapoint2	2	3	3	4	4	4

Figure 22 and Figure 23 show the various standard elements that make up a requirement paragraph with the help of noise certification requirements of the Matternet M2. A standard equation element of requirement paragraphs enforces the usage of such equations for data correction/adjustment for consistency among all applicants and/or test runs. Similarly, a standard requirement is naturally a part of a requirement paragraph that spells out a metric and the corresponding threshold that needs to be met. In parallel with the requirement breakdown process, the compatibility of existing standards with the rapidly evolving UAS category vehicles is analyzed. This analysis helps assess alternative approaches that could enhance the effectiveness of these standards. One such study targets the confidence interval requirement shown in Figure 22. Another study assessed the suitability of the duration adjustment equation highlighted in Figure 23.



(26) Noise Evaluation and Calculations—Calculation of Noise Levels [1]: The adjustment for off-reference altitude may be approximated from: The minimum sample size acceptable for the aircraft flyover certification measurements is six. The number of samples must be sufficient to establish statistically a **90 percent confidence limit** that does not exceed **±1.5 dB(A).**

Figure 22. Requirements breakdown highlighting standard requirement element.



$< \mathbf{delta} > \mathbf{J1}\ \boldsymbol{proposal} = \boldsymbol{k}\log_{10} {}^{H_T}/_{H_{ref}}$

If a **reduction** of **10%** (for example) in **interval width** is not seen after **3 more runs** (for example) beyond the **minimum 6 runs** already specified additional runs are not necessary

Figure 23. Model-based systems engineering certification framework version for unmanned aerial systems (UAS) to test category flexibility in equivalent certification procedures.

With the MBSE model, testing data can be validated against the requirements instantly after processing. For the convenience of the users, data should be populated in the form of an instance table shown in Table 4, aligning data to each corresponding constraint. The MBSE model validates data provided to each constraint instantly.

The workflow proposed is extended to an integrated framework for flexible assessment of the certification process and is expected to be reusable for a broader set of UAS configurations, as highlighted in Figure 23.

Task 3.3 Develop a Full Noise Test Plan

The certification framework for UASs developed under Task 3, and the use of the PIM completed under Task 4, allow our team to measure process flexibility, efficiency, complexity, and other figures of merit as part of comparing alternatives to the baseline. Framing this problem as a decision-making problem in this context, an “alternative” would be a version of the baseline certification process with a specific combination of a testing plan, instrumentation selection, and a setup for measurements and processing methods, as dictated by a possible equivalent procedure.

A typical flight test procedure can be divided into five major sections corresponding to four days of carrying out different activities or tasks, as shown in Figure 24. These sections are not necessarily carried out over consecutive days as any two sequential sections can be separated by days, if not months, depending on the testing campaign and the scheduling and planning of the parties involved.

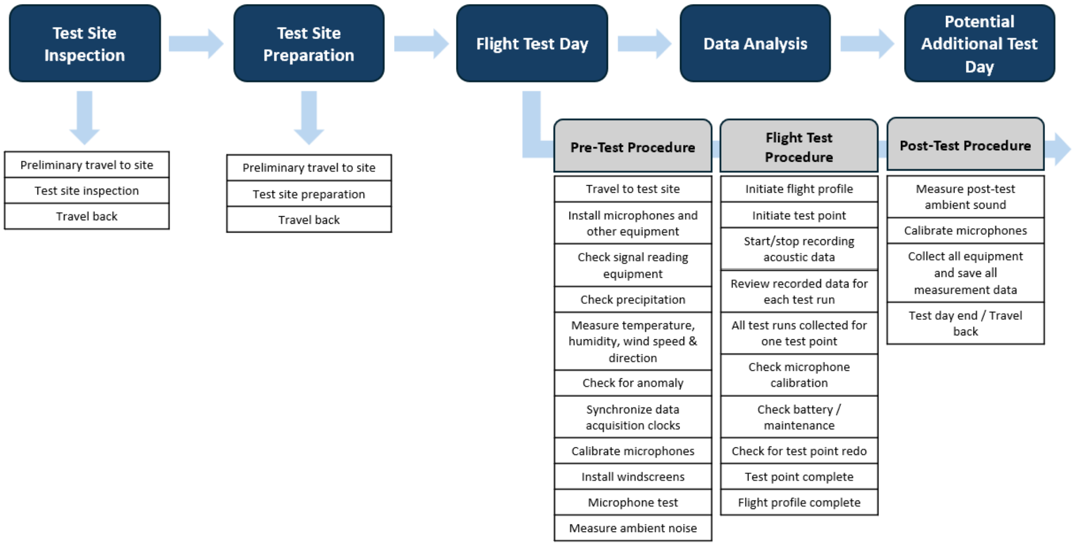


Figure 24. Outdoor noise testing procedure layout for unmanned aerial systems (UAS) noise measurements.

The flight test procedure can be described in the following steps (refer to Figure 24 for the detailed steps for each day of the testing process):

(1) Test Site Inspection. The team visits the potential test site to evaluate its suitability for conducting noise testing. This consists of assessment of the site location and surroundings in terms of proximity to noise-sensitive areas, weather conditions, and levels of background noise (e.g., traffic, birds, construction noise, or sound reflections off nearby buildings). The type of ground surface is also important as it could influence the noise measurement results. Common ground surfaces considered can include grass, concrete, asphalt, and open terrain. Grass tends to be the most preferred ground surface due to its ability to absorb sound and reduce sound reflections compared to hard surfaces; however, this requires the grass to be well maintained and free from tall vegetation. The elevation and uniformity of the ground surface are also crucial to avoid measurement inconsistencies. The overall site area is also evaluated by checking whether it can properly accommodate equipment installation, and distances and altitudes required for flight tests. Following this inspection, the test site is either approved, if deemed appropriate for the testing requirements, or denied, if it does not meet certain criteria or would lead to test measurement complications or inconsistencies. The necessary permits for conducting UAS flights at the selected location and ensuring regulatory compliance are obtained.

(2) Test Site Preparation. Once the test site is approved and permits are obtained, a second visit to the test site is necessary to prepare the site prior to the actual flight test day. This consists of clearing the site of any obstacles or potential hazards, mowing grass, if needed, and marking the positions of microphones and other equipment installation. This requires having a clear flight plan for the specific flight paths, altitudes, and maneuvers to be performed by the UAS on the flight test day. The UAS to be flown is also inspected to ensure it is functioning properly prior to the flight test day.

(3) Flight Test Day. The flight test day can be delineated into three main action lists:

- Pre-test Procedure: All microphones, recording equipment, and other equipment are installed and deployed. Weather measurements are initiated, and microphones are calibrated and tested prior to the installation of windshields and measurement of ambient noise. Throughout this procedure, multiple checks are conducted to ensure proper functioning of all devices and adequate meteorological conditions for testing.
- Flight-test Procedure: Flight test profiles (i.e., flyover, hover, takeoff, and landing, etc.) are initiated. Within each flight profile, multiple test points can be conducted under different conditions including altitude, weight, and speed. To ensure the accuracy and reliability of measurements, each test point is repeated for a minimum of six test runs. After the completion of each test point, multiple checks are carried out to assess the need for microphone recalibration, maintenance, or battery changes for UASs, or a complete redo of the test point upon the detection of any anomalies or inconsistencies in the measurements.
- Post-test Procedure: Once all flight profiles are completed, the ambient sound is measured, the microphones are calibrated, all microphones and equipment are collected, and measurement data are saved.

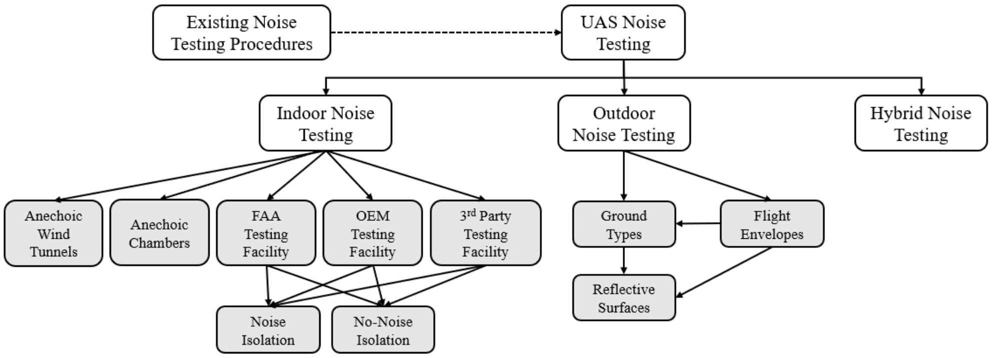


Figure 25. Noise testing types for unmanned aerial systems. FAA: Federal Aviation Administration, OEM: Original Equipment Manufacturer.

(4) Data Analysis. The data collected during the flight test day are postprocessed and analyzed. Raw measurements are translated in terms of noise metrics of interest, and any sources of inconsistency or interference with the measurements can be revealed. Consequently, the need for replacement or additional measurements is decided at this step.

(5) Potential Additional Test Day: Based on the results of the data analysis from the flight test, an additional flight test day might be necessary. This would either consist of a partial repeat of some test measurement points or a full flight retest if significant interference appears to have been present throughout the entire flight test day or throughout a major of the flight test.

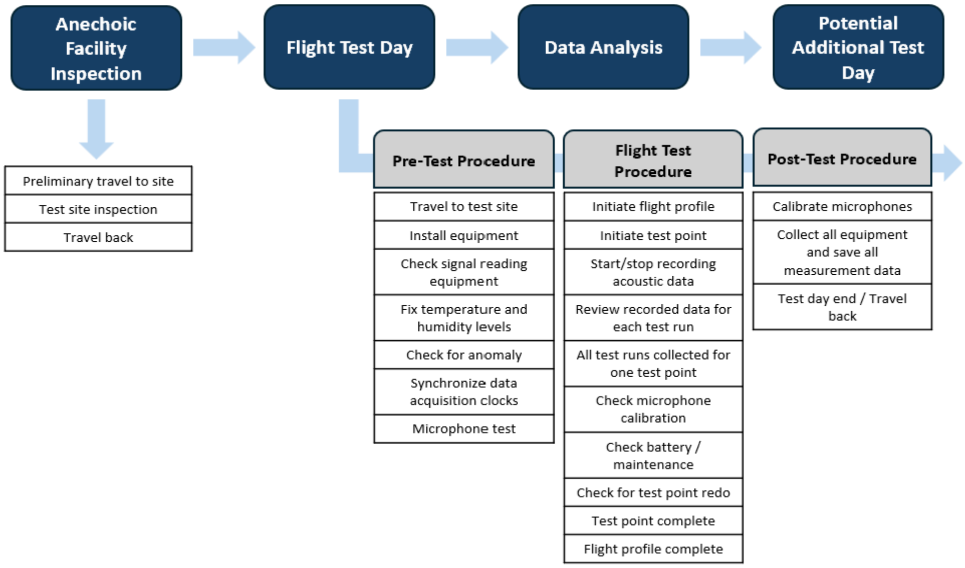


Figure 26. Indoor noise testing procedure layout for UAS noise measurements.

Similarly to the outdoor noise testing procedure for UASs described above, an indoor testing procedure can be formulated for UASs that can be tested in an enclosed space such as anechoic chambers or anechoic wind tunnels (Figure 25). The indoor testing consists of a smaller number of phases and steps considering the controlled nature of the testing environment which reduces the complexity of tasks to be carried out and increases the likelihood of measurements success due to the lack of weather or background noise interferences. Consequently, the corresponding procedure (Figure 26) does not require any travel for test-site preparation nor any continuous tracking of weather changes. Moreover, microphone installation and pre-calibration tasks are also eliminated as these are usually installed and calibrated beforehand by the facility. Additionally, the use of windscreens, previously needed for outdoor testing due to wind interference, is no longer essential.

After the model has been calibrated with inputs and parameter definitions that will be obtained from noise testing data resulting from ASCENT Projects 077 and 094, the model will rely on statistical analysis and an identification of process bottlenecks and showstoppers. Another set of metrics of interest will target the impact quantification of process complexities and will be used to indicate gaps and further drive certification process simplification using technologies and estimation methods (e.g., virtual sensing and instrumentation), where process steps could be reduced or eliminated.

As a means of facilitating a scenario-based parametric decision-making capability, the ASCENT Project 061 team has been developing an interactive visualization environment. Through the use of visual representations of the process and key analysis outputs, this environment serves as a user-friendly interface for requirement validation, exploration of process alternatives and their impacts, detection of process shortcomings and gaps, and ranking for the selection of test plans, instrumentation, and noise measurement data analysis against user-set criteria. The ranked alternatives are validated through an assessment of the equivalency for a procedure to standard regulatory practices. A notional representation of the final version of this environment is shown in Figure 27.

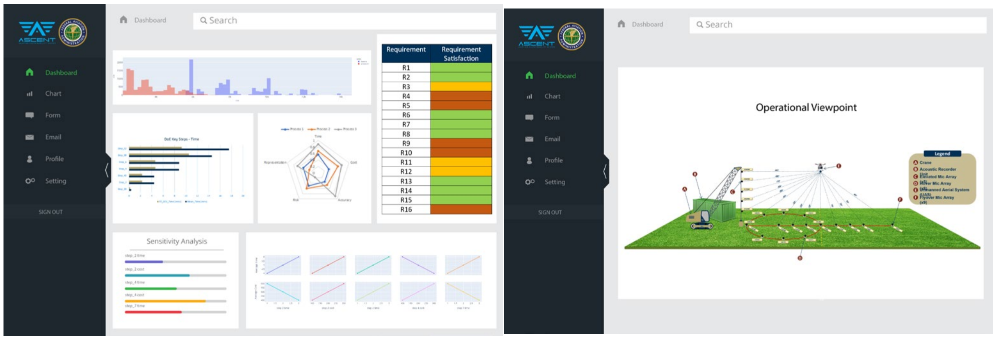


Figure 27. Graphical user interface for process specification.

As interactive dashboard development is often approached as a spiral development; the capabilities and features included in the current version are as follows:

- Histograms to visualize each metric of a given procedure. To compare procedures, it may be helpful to overlay the histograms for the respective procedures to visually compare time, cost, etc.
- Sensitivity plots to help select from alternative procedures to improve upon the current baseline. These sensitivities can indicate how robust an alternative is to unforeseen variability in the procedure steps in terms of time or cost it takes to complete the step. For example, how sensitive the overall cost improvement (with respect to the baseline) of an alternative is to the cost it takes to complete the alternatives' first step. This information can be presented to the decision maker in the form of a matrix of plots like the prediction profiler plot in the JMP statistical software.
- For multivariate and multicriteria problems, a spider chart (radar plot) is used to compare process alternatives against multiple criteria. This chart can help to drive the evaluation of all tested process alternatives and map the strengths and weaknesses of each alternative against the prioritized evaluation criteria.
- The highest ranked process as a chain of events to rank order key steps identified by the PIM in the order of importance for a given procedure.
- A requirements satisfaction section to present an assessment review of whether requirements are being met, which includes providing guidance toward the exploration of procedures and technologies that would help close any gaps and meet all requirements. In this part, the focus is on data analytics supported by the Monte Carlo process simulations using probabilistic inputs. Hence, the results are typically in the form of distributions for the metrics of interest, and allow for exporting means, median values, and cumulative distribution functions to assess whether constraints and requirements are being met.
- A high-level concept graphic (OV-1) charts to capture the physical representation of the test setup and easier communication with OEMs and decision makers as needed.

Using this visualization environment, decision makers can determine the feasibility of alternative procedures, compare alternatives relative to the baseline, and downselect between alternative procedures based on sensitivity to input values. On the actual model demonstrator, alternative procedures will be compared based on sensitivities. The sensitivity plots, along with the histograms and the complementary plots, will be used to select an alternative to the current baseline procedure that has the desired balance between mean performance, variability, and robustness in terms of relevant metrics such as overall time and cost of the procedures.

To enable the multicriteria, parametric, and interactive capability for rapid exploration of certification alternatives, the PIM, which executes a process simulation through Markov chains[1] and graph analysis, can allow probabilistic Monte Carlo simulations for investigating the limitations of each process alternative. This capability is primarily the focus of Task 4 and is presented in the following section (Figure 36 of the Task 4.1 Develop alternative testing procedures using the elements library) of this report.

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[1] A Marcov chain, named after Andrey Markov, is a mathematical stochastic process (framework) for describing the sequence and/or states where transitions occur in a given state that are dependent on the probability of the state attained in the previous event and time elapsed (e.g., the probability that n+1th steps will be x depends only on the nth step, not the complete sequence of steps that came before n).

Task 3.4 Implement a Validation Process

A particular instance to illustrate the analysis of alternatives proposed is regulatory paragraph J36.205(b) of 14 CFR § 36, Appendix J, which prescribes the method of adjustment for test flight altitudes during flyover noise measurements that deviate from the reference altitude prescribed in the regulatory paragraph 14 CFR § 36 J36.3(c). Figure 28 (Figure 5 from Volpe test campaigns SEL Duration Adjustment Studies [Senzig et. al., 2018]) shows that the higher the test flight altitude deviation is from the reference altitude on which the correction curve is based, the higher the error is that results from the adjustment. The test campaigns by Volpe (Senzig et al., 2018) evaluated these errors by means of the difference in adjusted noise measurement values and actual noise measurement values at various altitudes. Referring to the morphological matrix discussed earlier (refer to Table 3; Task 1.3), an alternative procedure can emerge from any one of the procedural steps such as data processing methods, as in this particular use case. This again bolsters the need for a traceable platform that has the capability to conduct a holistic assessment of all potential certification bases.

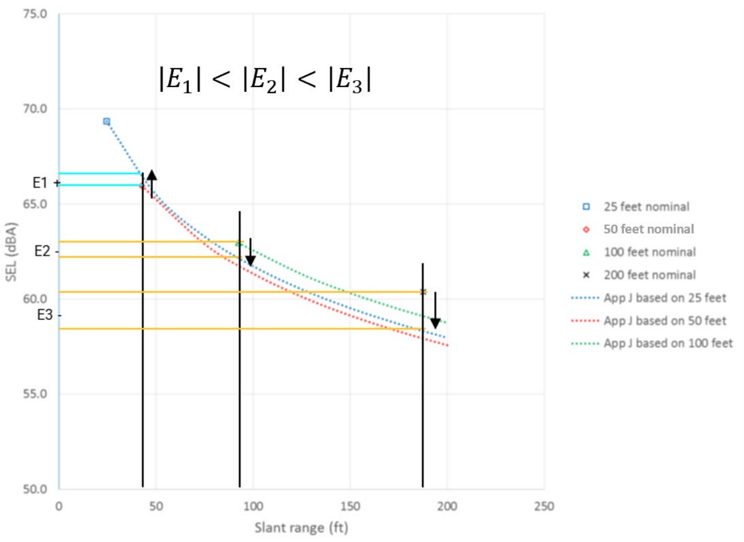
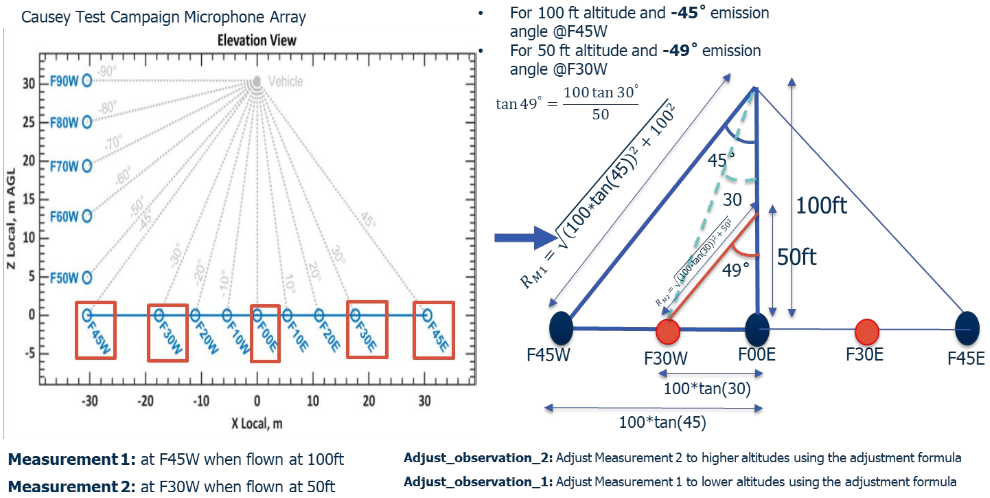


Figure 28. 14 CFR § 36 Appendix J duration adjustments applied to various altitudes (Figure 5 of SEL Duration Adjustment Studies [Senzig et. al., 2018]).

Figure 29 below shows the microphone array configuration employed by the Causey testing campaign (James et al., 2021) that generated data analyzed by the Cutler-Wood et al. (2022). The same experimental data were used to conduct the duration adjustment study discussed in this section in the context of analysis of alternatives.



Measurement 1: at F45W when flown at 100ft

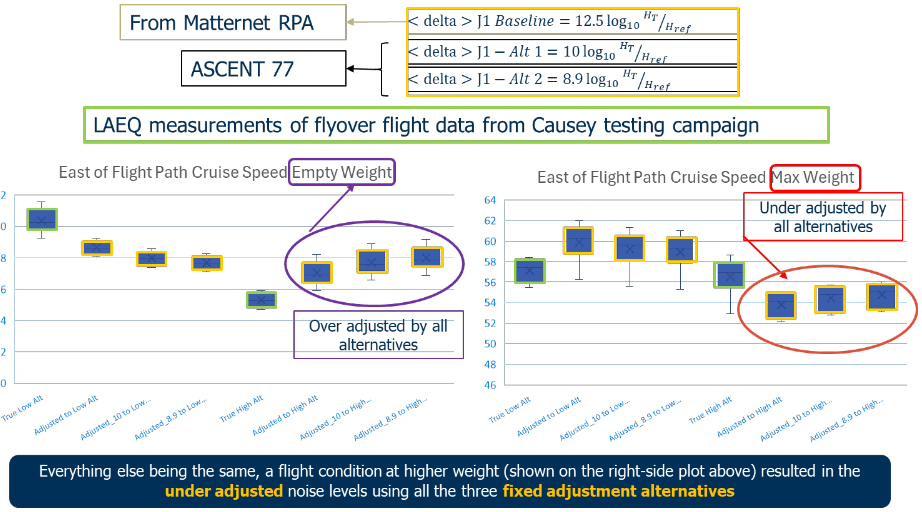
Measurement 2: at F30W when flown at 50ft

Adjust_observation_2: Adjust Measurement 2 to higher altitudes using the adjustment formula

Adjust_observation_1: Adjust Measurement 1 to lower altitudes using the adjustment formula

Figure 29. Causey microphone configuration and measurement nomenclature.

Each alternative procedure can have different ramifications on different paragraphs of a regulatory noise standard. Consider, for instance, the alternatives illustrated in Figure 30 for the duration adjustment equation. The variation of noise with respect to emission angles is represented using noise spheres in Cutler-Wood et al. (2022). To determine the utility of the proposed alternative in the context of the duration adjustment requirement alone, it is necessary to know the effects of emission angle and flight profile parameters such as hover flight altitude and weight of the vehicle on the variability in the measurement. It can be seen from Figure 30 that various fixed factor adjustments proposed do not necessarily guarantee a conservative adjustment of the true measurements to different altitudes. The fixed factor adjustments are specified in the RPA corresponding to the Matternet M2 (FAA, 2022), the other RPAs (FAA, 2023) issued by the FAA. Hence, as highlighted in Figure 23, it is worth considering vehicle specific k-factor adjustment regimen given the wide variety of configurations with varied noise generation and propagation characteristics emblematic of the UAS category.



Everything else being the same, a flight condition at higher weight (shown on the right-side plot above) resulted in the **under adjusted** noise levels using all the three **fixed adjustment alternatives**

Figure 30. Application of the fixed factor duration adjustments to the noise measurements.

Figure 31 shows the microphone array configuration employed by the FAA and collaborating researchers (James et al., 2021) to acquire noise data necessary to understand the effects (Cutler-Wood et al., 2022). The vehicle deployed for the experimental campaign belongs to the small UAS category.

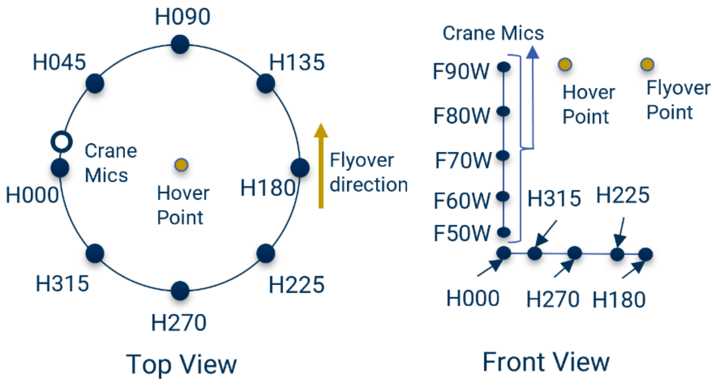
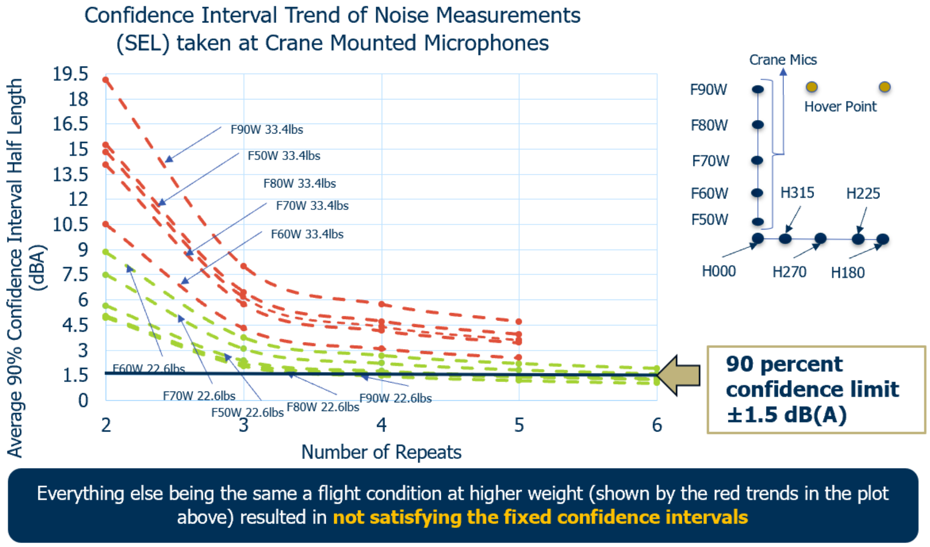


Figure 31. Experimental microphone array configuration (not to scale).

Experimental results consisted of higher-weight and lower-weight flights that were flown at an altitude of 100 ft and repeated five and six times, respectively. Our team evaluated the average confidence interval of SEL measurements of various subsets of a given number of repeats and plotted the results as shown in Figure 32. Figure 32 highlights the effect that vehicle weight has on variability in noise measurement. It can be observed that a higher weight configuration results in higher variability. Figure 32**,** however, does not illustrate a strict relationship in emission angle and weight, and further investigation may highlight the same. The ASCENT Project 061 team also observed that a greater number of runs is required to achieve a confidence interval limit of ± 1.5 dBA (SEL) at higher weight configuration. In view of this, it is proposed if a reduction of 10% (for example) in interval width is not seen after three additional runs (for example) beyond the minimum of six runs already specified, additional runs are not necessary, noting that further reduction variability may not be possible for the given combination vehicle configuration and test flight profile.



Everything else being the same a flight condition at higher weight (shown by the red trends in the plot above) resulted in **not satisfying the fixed confidence intervals**

Figure 32. Effects of vehicle weight and emission angle on noise variability in hover flight. SEL: sound exposure level.

Figure 33 shows the average confidence interval trends for a flyover flight condition that was repeated the highest number of times. Although this flight condition is different from the hover flight condition, it highlights the trend of the average confidence interval of SEL over a higher number of runs. Hence, our team noted that although fewer microphones are required for the alternative method as shown in in the left panel plot of Figure 30, the number of repeats required to achieve the confidence interval limit make the alternative method, as shown in the right panel plot of Figure 30, preferable. Ultimately, to arrive at a decision, the costs and times of additional microphones and their setup need to be compared with those of additional flights.

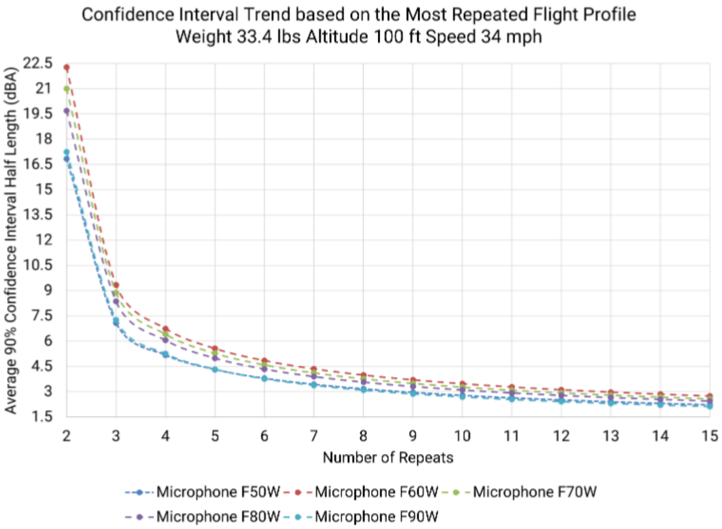
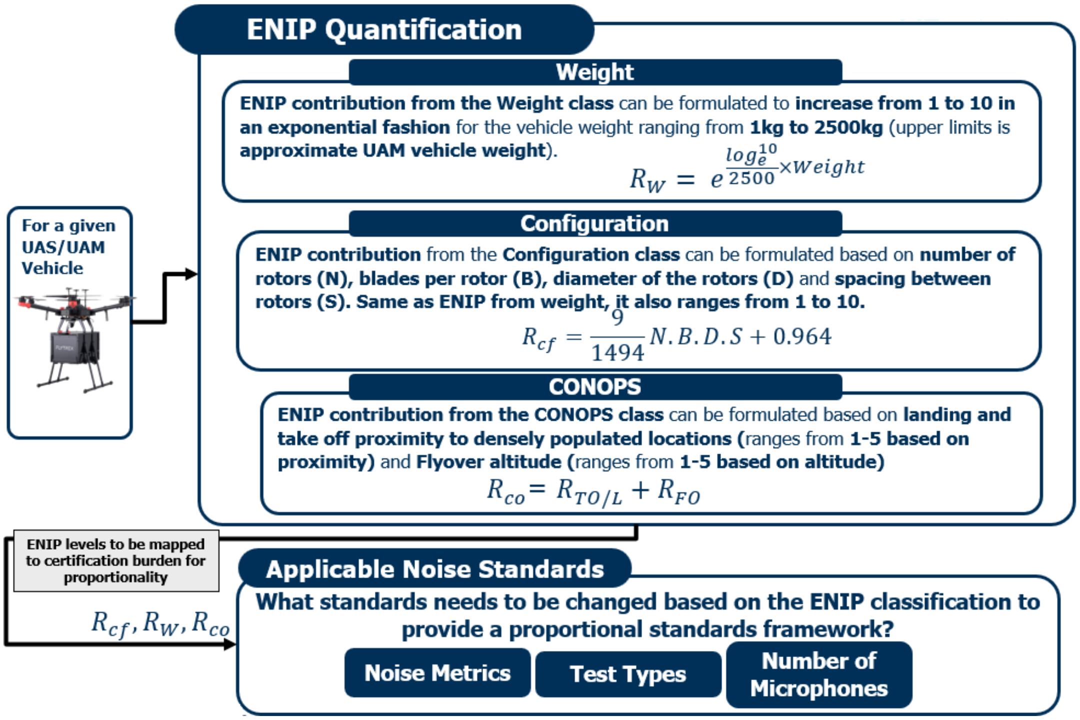


Figure 33. Effects of emission angle on noise variability in flyover flight.

Environmental Noise Impact Potential

As discussed under Task 1, the risk-based demarcation by the EASA takes operational parameters into consideration while demarking the noise standards. However, the design parameters such as design configuration and weight can enhance the demarcation exercise given their contribution to the Environmental Noise Impact Potential (ENIP). Framework in **Error! Reference source not found.** is proposed for the purpose of evaluating the same.



ENIP contribution from the Weight class can be formulated to **increase from 1 to 10 in an exponential fashion** for the vehicle weight ranging from **1kg to 2500kg** (upper limits is **approximate UAM vehicle weight**).

$$R_W = e^{\frac{log_e^{10}}{2500} \times Weight}$$

ENIP contribution from the **Configuration class** can be formulated based on **number of rotors (N), blades per rotor (B), diameter of the rotors (D)** and **spacing between rotors (S). Same as ENIP from weight, it also ranges from 1 to 10.**

$$R_{cf} = \frac{9}{1494} N.B.D.S + 0.964$$

ENIP contribution from the CONOPS class can be formulated based on **landing and take off proximity to densely populated locations** (ranges from **1-5 based on proximity)** and **Flyover altitude** (ranges from **1-5 based on altitude)**

$$R_{co} = R_{TO/L} + R_{FO}$$

R_{cf}, R_W, R_{co}

What standards needs to be changed based on the ENIP classification to provide a proportional standards framework?

Figure 34. Environmental Noise Impact Potential (ENIP) Framework. CONOPS: configuration and concept of operations, UAM: urban air mobility, UAS: unmanned aircraft systems.

Engagement with ASTM F38

Advancing Standards and Transforming Markets (ASTM) working group F38 found the methodology proposed here for standards setting suitable for the FAA Part 108 Beyond Visual Line of Sight Operations (BVLOS) for commercial UAS operations noise certification. The committee members and the researchers on ASCENT Project 061 team met and discussed the collaboration opportunities to further effective rule making efforts. The meeting took place on August 21, 2025. The FAA proposed a rule on August 7, 2025 for scaling up the UAS BVLOS operations and integrating them into National Air Space safely. The commenting period on this proposed rule ended on October 6, 2025.

Milestones

See the milestones under Task 1.

Major Accomplishments

- Developed metrics and integrated the PIM under a parametric interactive decision support environment. The concept has been demonstrated through a minimum viable project exercise.
- Formulated and applied to the PIM to a typical plan for UAS noise testing.
- Conducted a preliminary analysis of noise measurement data and utilized resulting insights for requirement analysis.

Publications

Published Conference Proceedings

Ali, H. E., Ravikanti, B., Balchanos, M. G., Harrison, E., & Mavris, D. (2025). MBSE Enabled Requirement Verification for a Traceable Regulatory Analysis Framework of UAS Noise Certification Standards. AIAA SCITECH 2025 Forum (p. 0367).

Mali, H., Geneti, N. F., Balchanos, M. G., Harrison, E., & Mavris, D. (2025). A Process Evaluation and Visualization Framework for Unmanned Aerial System (UAS) Noise Certification Testing. *AIAA SCITECH 2025 Forum* (p. 0368).

Balchanos, M., Ravikanti, B., Ali, H., Mali, H., D Harrison, E., & N Mavris, D. (2024, September 9-11). *A Regulatory Analysis and Process Improvement Decision Support Framework for Unmanned Aerial System (UAS) Noise Certification* [Conference presentation]. Quiet Drones 2024 Symposium, Manchester, United Kingdom.

Awards

None.

Student Involvement

The full student team (Hussein Ali, Nathaniel Geneti, Hajar Mali, Martin Poretti and Balaji Ravikanti) has participated in brainstorming sessions toward formulating the integrated certification process assessment framework for UAS.

Plans for Next Period

- Project ended on September 30, 2025.
- Publish peer-reviewed journal articles with *AIAA Journal* and AIAA SciTech.

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Federal Register. (2025). *FAA Part 108 UAS BVLOS Proposed Rule: Normalizing Unmanned Aircraft Systems Beyond Visual Line of Sight Operations*. https://www.federalregister.gov/documents/2025/08/07/2025-14992/normalizing-unmanned-aircraft-systems-beyond-visual-line-of-sight-operations

Task 4 - Develop Alternative Procedures and Assess Their Performance with Existing Tools (Case Study)

Georgia Institute of Technology

Objectives

Task 4 seeks to explore options for evaluating noise certification within the MBSE certification framework. The purpose of this task is to allow a performance baseline to be established for current procedures and to allow for the evaluation and comparison of more flexible process alternatives as they are formulated within Tasks 2 and 3. The breakdown of tasks under Task 4 is as follows:

Task 4: Develop alternative procedures and assess their performance with existing tools
  4.1 Develop alternative testing procedures using the elements library
  4.2 Transfer alternative procedures to the PIM
  4.3 Report on the performance of the alternative procedures
  4.4 Develop a proof-of-concept demonstration of the PIM capabilities

Research Approach

The goal of Task 4 is to identify process modeling approaches for the purpose of simulating and evaluating the performance of a noise certification procedure. Task 4 delivers a solution that, in a broader sense, is referred to as the PIM. Tasks 4.1 to 4.3 focus on PIM implementation, whereas Task 4.4 integrates the PIM into the current MBSE framework. The PIM must analyze the process performance and interface with the verification model for completing steps regarding requirements and compliance. The PIM must also be flexible and reusable within the verification thread and must accommodate UAS configurations. An overview of the integrated verification thread and the PIMs is shown in Figure 35.

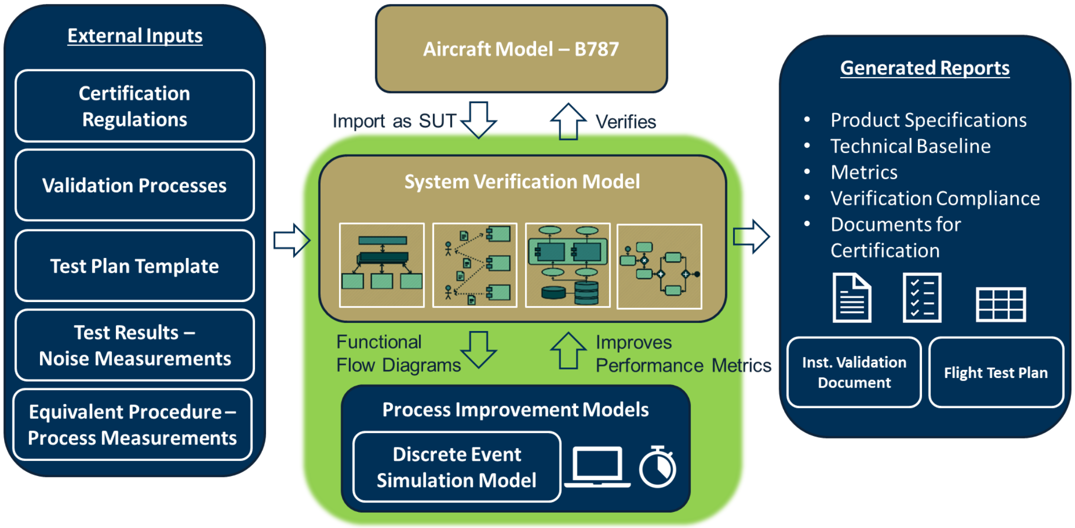


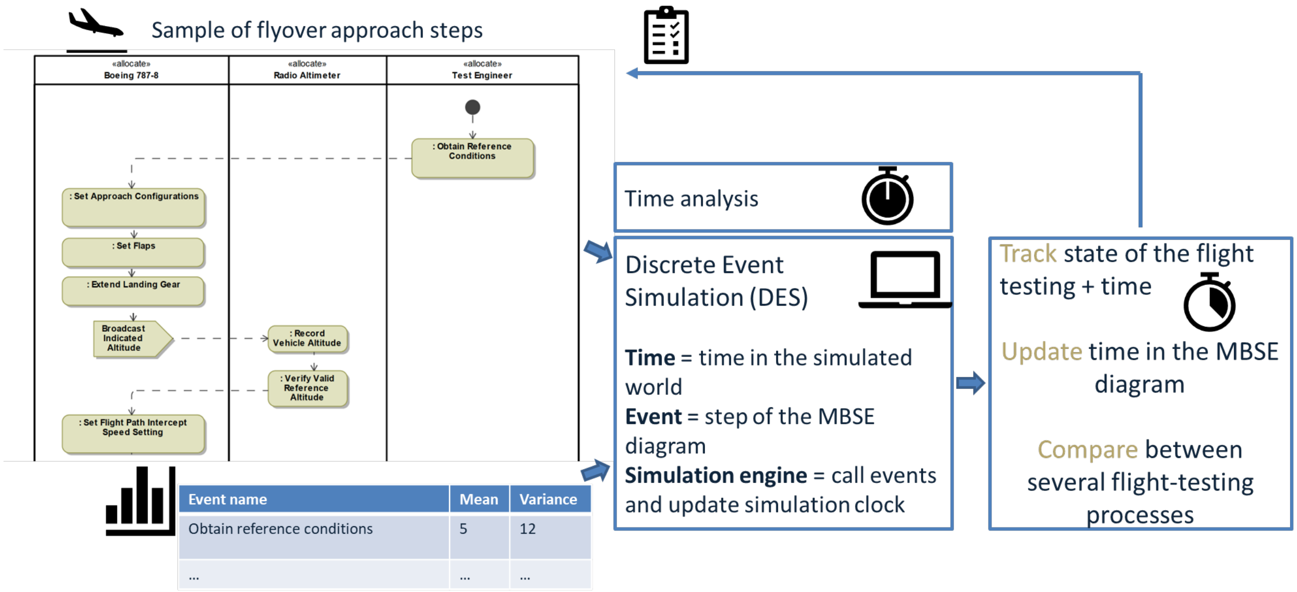
Figure 35. Integration of the process improvement model within the model-based systems engineering certification framework. SUT: system under test.

Task 4.1 Develop Alternative Testing Procedures Using the Elements Library

The team has completed a literature review on process modeling methods to enable process simulation. These methods are listed below:

- DES, where a clock tracks the duration of the transition between model states
- Agent-based simulation methods
- System dynamics
- MCMC simulation methods

These techniques are evaluated on the basis of their ability to capture and simulate actual industry-applied procedures, and to interface with the verification thread. For simulating a simple process that is representative of transport category certification, the DES modeling approach appears to be the most effective. To demonstrate feasibility, a proof-of-concept version was developed using the DES method in a Python-based environment. The chosen example covered the testing process for a flyover approach, as shown in Figure 36. The objective was to demonstrate that a process model, as defined in the MBSE framework, can be simulated using DES. With the MBSE model states imported, DES can track the clock and return time points at each event conclusion. The DES results are then fed back as input in turn updating the process diagram in the verification model, which then checks the process model against requirements and compliance.



Time = time in the simulated world
Event = step of the MBSE diagram
Simulation engine = call events and update simulation clock

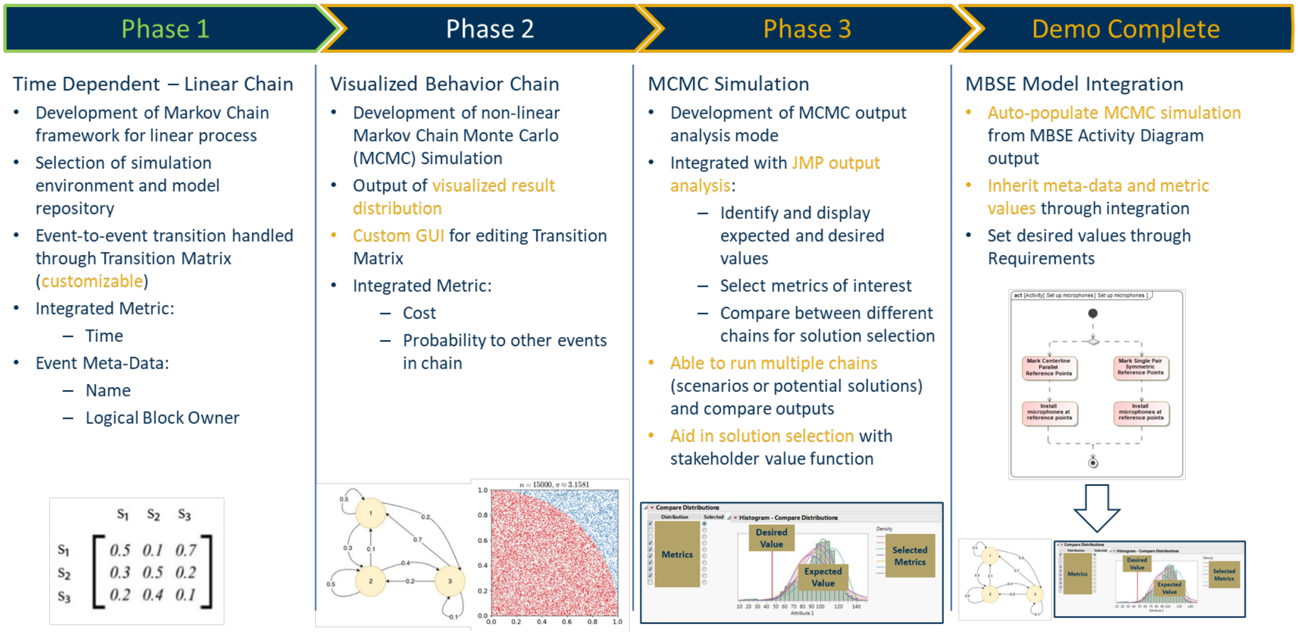
Event name	Mean	Variance
Obtain reference conditions	5	12
…	…	…

Figure 36. Discrete event simulation (DES) for a flyover approach. MBSE: model-based systems engineering.

However, because flight testing procedures are impacted by uncertainties, a different modeling approach is needed. To account for uncertainties, a probabilistic model using Markov chains has been developed to improve the accuracy of how interactions and emerging effects are captured. This approach is better suited to support use cases, with the objective of further process simplification, especially for flight testing portions, instrumentation setup, and measurement systems. This simplification could involve eliminating or replacing steps and potentially using advanced data-driven or physics-based modeling approaches as a substitute.

Because of the extension of DES to Markov chain approaches and the need for large samples, the ASCENT Project 061 team adopted the MCMC approach, where a Markov chain model is used to run a Monte Carlo study to collect sample runs, given an input probability matrix and stakeholder value function. Each run is associated with an incurred time, cost, and accuracy penalty. The output is provided in the form of activity diagrams and responses that are fed back to the verification model within the MBSE framework. Through the requirement model within the MBSE framework, the MCMC simulation data are imported to perform acceptance–rejection sampling, where each run (with its associated metric) is accepted or rejected by requirements/constraints within the verification model. The format of the MCMC simulation data follows the form of a step-by-step sequence (similar to a DES).

Summarizing the development of the PIM, the implementation path is shown in Figure 37, which illustrates the interface with the verification model. Using a similar flyover approach plan example as in Figure 36, the process model informs the PIM, which converts the flyover approach test into an executable simulation model. Based on the type of requirement test selected by the user, the appropriate response values, parametric settings for baseline values (i.e., time, cost, resources, disruption risks, accuracy penalty, etc.), and distributions for Monte Carlo simulations are chosen. The Monte Carlo simulation then generates the PIM metrics and prepares the dataset for verification.



Phase 1

Phase 2

Phase 3

Demo Complete

Time Dependent – Linear Chain

- Development of Markov Chain framework for linear process
- Selection of simulation environment and model repository
- Event-to-event transition handled through Transition Matrix (customizable)
- Integrated Metric:
  - Time
- Event Meta-Data:
  - Name
  - Logical Block Owner

$$\begin{array}{c|ccc} & S_1 & S_2 & S_3 \\ \hline S_1 & 0.5 & 0.1 & 0.7 \\ S_2 & 0.3 & 0.5 & 0.2 \\ S_3 & 0.2 & 0.4 & 0.1 \end{array}$$

Visualized Behavior Chain

- Development of non-linear Markov Chain Monte Carlo (MCMC) Simulation
- Output of visualized result distribution
- Custom GUI for editing Transition Matrix
- Integrated Metric:
  - Cost
  - Probability to other events in chain

MCMC Simulation

- Development of MCMC output analysis mode
- Integrated with JMP output analysis:
  - Identify and display expected and desired values
  - Select metrics of interest
  - Compare between different chains for solution selection
- Able to run multiple chains (scenarios or potential solutions) and compare outputs
- Aid in solution selection with stakeholder value function

MBSE Model Integration

- Auto-populate MCMC simulation from MBSE Activity Diagram output
- Inherit meta-data and metric values through integration
- Set desired values through Requirements

Figure 37. Functional development plan based on a process improvement model. GUI: graphical user interface, MBSE: model-based systems engineering, MCMC: Markov chain Monte Carlo.

For this task, the literature search, exploration of modeling options and selection, and proof-of-concept implementation are now completed.

Task 4.2 Transfer alternative procedures to the PIM.
With the PIM model now available in a flexible and customizable format, in Task 4.2 our team sought to expand the process simulation and analysis toward metrics that will link to use case objectives and process selection of improved alternatives.

The selected metrics should allow for a quantitative comparison of current and proposed streamlined noise certification process options. The updated list of identified metrics is as follows:

- Time: The schedule cost incurred to complete event.
- Cost: The budget cost incurred to complete event.
- P(Failure): The probability of repeating an event or reverting to a previous event (does incur time and cost [full or partial] in each occurrence).
- P(Success): The probability of moving out of the current event.
- Accuracy penalty: The impact on overall accuracy value for executing the event (does not incur an additional cost in each occurrence).
- Process complexity metrics: These metrics are one of the latest additions to the model and allow the model to capture the level of uncertainty and risks corresponding to a specific testing procedure. More complex procedures are highly susceptible to causing significant schedule and budget overruns.

The proposed integrated model uses a system verification model with external inputs, such as current certification regulations, validation processes, and test plan templates. This results in an interconnected model for the UAS, referred to as the SUT, which evaluates the validity of a certain certification procedure and generates alternative procedures suggesting one or a combination of modifications related to the utilized noise measurement metric, microphone type or array design, or flight profile (i.e., flyover, hover, vertical takeoff/landing, etc.). Figure 38 provides a general overview of the integrated structure of the system verification model, the PIM, and the visualization environment.

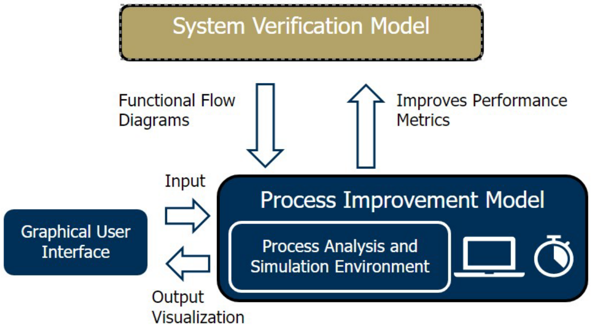


Figure 38. Integration of system verification model, process improvement modeling, and graphical interface.

In addition to the flight test procedure diagrams describing the sequence of events constituting the flight tests, different detailed reports can be generated as outputs of the system verification model. The PIM assesses the performance of the baseline flight test procedure and other alternative procedures in terms of overall time and cost. The PIM captures a typical noise testing process. Certain events within that process have feedback loops indicating that one event or a set of events is to be repeated due to the detection of anomalies or calibration issues. Hence, some events can have different outcomes and, depending on the likelihood of each outcome, the overall flight test sequence would differ and lead to a different overall time and cost of the entire process. This steers the focus toward a probabilistic modeling approach, in which it is desirable that each event exclusively depends on the previous event. Moreover, to properly account for uncertainty and risks in predictions and decision-making, it is crucial for these flight tests to be simulated multiple times. With all these elements taken into consideration, a suitable approach for modeling a flight test procedure is using a Markov chain. To maintain a simplified terminology for the PIM, the flight test procedures extracted from the system verification model are to be considered flight test processes and the events are to be referred to as steps.

The PIM implements a Matlab script incorporating the mathematical representation of the flight test process to be analyzed using Monte Carlo simulations. Two Microsoft® Excel® files are used as inputs to the script; the first file includes all the steps of the flight test process and the probabilities of occurrence of each outcome, and the second file contains the assigned time and cost values for each step.

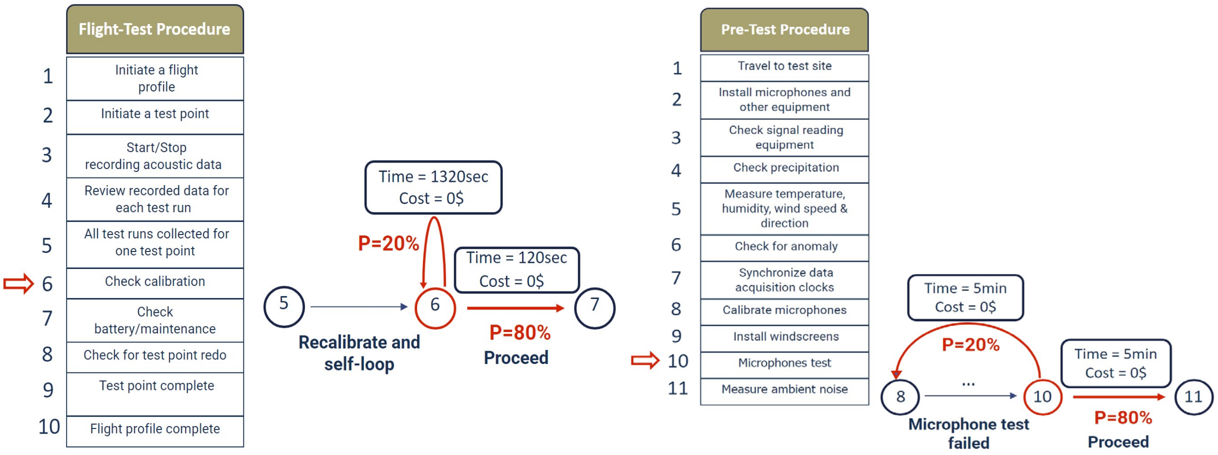


Figure 39. Example of self-loop (left figure) and feedback loop (right figure) within the noise testing process.

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As noise testing is captured as a stochastic process, most of the steps can lead to different outcomes depending on many factors, including human error, unstable weather conditions, equipment malfunction, unsatisfactory measurements, etc. These variations are modeled using feedback loops and self-loops in the Markov chain, in which the former represents the need to go back to a previous task in case an anomaly is detected, whereas the latter refers to the need to repeat the current task. Each potential outcome has a specific probability of occurrence assigned to it. Figure 39 portrays examples of a self-loop and a feedback loop within the process. In Figure 39, step 6 of the flight-test procedure consists of checking the calibration of the microphones after the completion of each test point. This step is crucial to avoid potential complications such as reducing confidence in the validity of noise test results, lacking a traceable chain of measurement standards, and impacting data comparability across multiple instruments. In this example, a probability of 20% is set for the need to recalibrate, which entails a longer time compared to the alternative outcome of not needing recalibration with 80% probability. Similarly, step 10 of the pre-test procedure consists of two potential outcomes for the microphone test; either the test fails, and the staff need to take the windscreens off, recalibrate the microphones, reinstall the windscreens and test again (probability of 20%), or the microphone test is successful (probability of 80%) and the following step is initiated.

In addition to evaluating the effectiveness and efficiency of different testing alternatives in terms of their resulting time and cost, capturing and understanding the complexity of the testing layout is also crucial as it helps identify improvement points within the process to better streamline it and reduce the uncertainty and error proneness related to it.

Two categories of metrics have been implemented to quantify the complexity level of a testing procedure; four metrics that are dependent only on the structure of the noise testing process, and one metric that is dependent on the outcome of the Monte Carlo simulations. This simulation-dependent metric is the Redundancy and Rework Index (RRI), and it indicates the percentage of steps in the process that are redundant or have been reworked, such as measurement repetitions or microphones' re-calibration. This metric highlights areas in the process where efficiency improvements might be necessary to reduce the uncertainty level related to those steps and minimize repetitions and corrections, as follows:

$$RRI = \frac{R}{T} \qquad \text{(Eq. 5)}$$

where R is the number of repeated or reworked steps and T is the total number of steps.

RRI is computed for each Monte Carlo simulation. Since each of the 10,000 design of experiment (DoE) cases contains 10,000 Monte Carlo runs, the mean and standard deviation of RRI is calculated for each DoE case then calculated again over all cases to get a final mean RRI and standard deviation for the overall noise testing process. As for the process-dependent complexity metrics, these include:

- Cyclomatic Complexity (CC), which calculates the number of unique and independent paths (different sequence of nodes and edges) to go through the process such that full testing coverage is ensured, as follows:

  $$CC = E - N + 2P \qquad \text{(Eq. 6)}$$

  where E is the number of edges, N is the number of process steps, and P is the number of connected components.

- Control Flow Complexity (CFC), which indicates how much decision-making and iteration is present within the process based on the control flow structure, as follows:

  $$CFC = D + L \qquad \text{(Eq. 7)}$$

  where D is the number of steps with multiple potential paths and L is the number of feedback loops and self-loops.

- Decision Density (DD), which measures the concentration of decision points in the process (as shown in the following equation). A lower decision density value indicates fewer decision points leading to less uncertainty relative to the total number of steps. In contrast, a higher value would indicate the opposite.

  $$DD = \frac{D}{T} \qquad \text{(Eq. 8)}$$

- Process Entropy (PE), which measures the unpredictability in the process flow. A high level of entropy indicates that there are many possible task outcomes(paths), making the process more complex and more difficult to predict. Lower entropy, however, means fewer paths, and a more structured and predictable process.

  For a step i with j potential paths:

$$\sum_{j=1}^{n} p_{ij} = 1 \qquad \text{(Eq. 9)}$$

  where p_{ij} is the probability of occurrence of path j at step i.

  Process entropy for step i:

$$PE_I = -\sum_{j=1}^{n} p_{ij} \log\left(p_{ij}\right) \qquad \text{(Eq. 10)}$$

  Overall process entropy:

$$PE = \sum_{i=1}^{m} PE_i = -\sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij} \log\left(p_{ij}\right) \qquad \text{(Eq. 11)}$$

Task 4.3 Report on the Performance of the Alternative Procedures

The objective of Task 4.3 is to produce a baseline of a noise certification procedure simulation and to propose a calibration step, as process data become available from ASCENT Project 061 partners. The analysis workflow for the PIM module is shown in Figure 40. The goal of the workflow within the PIM is to analyze the complexity of the process and to identify potential bottlenecks by assessing time, cost, and node/step criticalities. The workflow is completed in three basic steps:

1. **Definition of test data:** This step includes a test plan, setup, instrumentation and recording information, and sound pressure level measurement data.
2. **Process representation as an event chain through graph modeling:** In this step, the process is converted and represented as a weighted directed graph. Each node represents a step in the process, and the edges represent transitions between steps. The progression through the steps is represented by probabilities and parameters at each step.
3. **Execution of the MCMC algorithm:** The simulation starts from a node, and a "roll the dice" (i.e., generate a random number) function is performed. Depending on the outcome and the probability of each path, the algorithm selects the next node. A learning factor is utilized to update the probabilities of progressing through the steps (increased probability the second time).

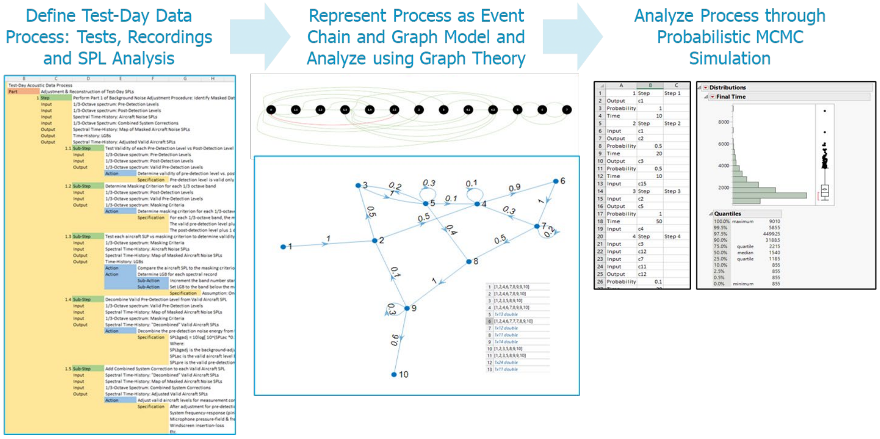


Figure 40. Analysis workflow based on the process improvement model. MCMC: Markov chain Monte Carlo; SPL: sound pressure level.

The analysis of different alternative procedures in noise flight testing relies on the evaluation of different performance criteria or metrics of interest to which the user may allocate different levels of importance. The outputs of this analysis heavily contribute to the decision-making alongside the regulatory adherence in which the requirements' satisfaction of each alternative procedure is evaluated. In the context of the suggested PIM, progression through the steps is associated with probabilities and parameters. Hence, tracking the propagation of these metrics of interest is enabled within the Monte Carlo simulations. Induced costs and time throughout the process are the focus of the current efforts. When combined with the sequencing of events of each process simulation, these outputs can provide insight into process complexity and induced risks and allow the anticipation of potential bottlenecks in the process.

Noise certification testing processes are represented using Markov chains within a probabilistic simulation environment. This approach relies on random variables, which are functions assigning real numbers to each potential outcome within the sample space of a random experiment. This approach also entails that every event solely depends on the previous event, thus preventing the propagation of uncertainties throughout the process. The entire process can be visualized using weighted directed graphs, in which every node represents a step within the noise testing process and the edges indicate the transitions between nodes. A valid representation of the certification testing process requires every node on the graph to be able to eventually reach the final step, thus ensuring process continuity by calculating the "connected components" in the graph. Figure 41 depicts the need to ensure continuity within the demonstrative process. The illustration on the left of Figure 41 depicts the demonstrative process in which step 7 cannot reach the final step; whereas the corrected Markov chain representation on the right of Figure 41 implements process continuity for each step.

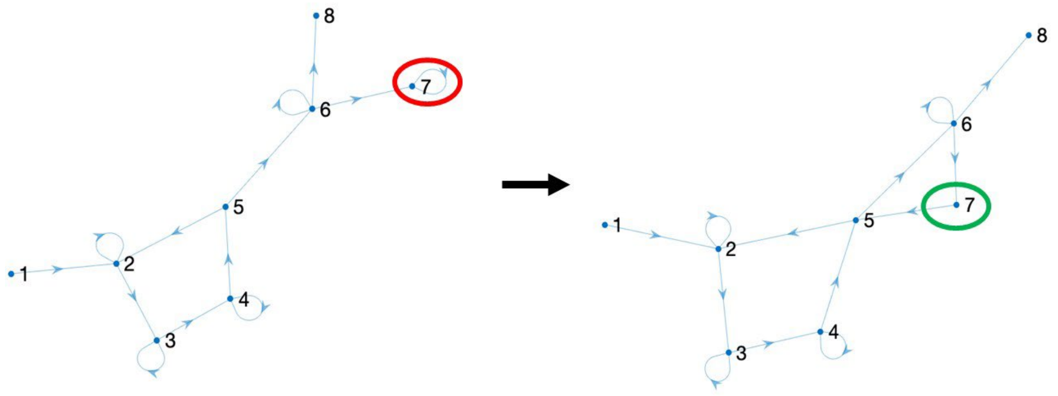


Figure 41. Illustration of process continuity in a sample flight test process.

Every edge of the Markov chain representation is assigned to a probability characterizing the likelihood of moving from one node to another, thus mapping different potential paths to be taken. The Monte Carlo method is implemented to achieve repeated random sampling during the simulation. This method generates a random number that is compared to the cumulative sum of the row corresponding to the current step of the transition matrix, which contains all potential probabilities connecting any two nodes. The next step is chosen once the random number is less than or equal to the smallest cumulative sum. Each Monte Carlo simulation follows a specific path that is dictated by the method. To achieve accurate estimates, the Monte Carlo simulation must be repeated multiple times by increasing the number of runs set within the Matlab script. This underlines an important trade-off between the accuracy of the results and the script execution time. In this work, the analysis was first exclusively targeting the most influential steps of the noise testing process as they will be the main sources of variation within the results. This approach allows for the reduction of computational time for PIM execution while ensuring the accuracy and reliability of the results. This can be accomplished by implementing PageRank centrality, which is a metric providing the average time spent at each node during a random process simulation. The average for each node is weighted according to the probabilities of reaching a node and the value of the associated parameter. These key (i.e., most influential) steps were varied in each simulation using DoEs. In addition to the identification of key steps, the code introduces the capability of detecting bottlenecks within the process, giving enough insight about steps susceptible to causing delays or complications within the process workflow.

Table 5. Identification of noise testing equipment and other expenses.

	Fixed Costs	Variable Costs
Equipment	Microphones	Batteries
	Windscreens	Personnel payment
	Weather sensors	
	Time-position tracker	
	Crane or poles (for elevated microphones)	
	Calibrators	
	Travel expenses	
	Test site rental	

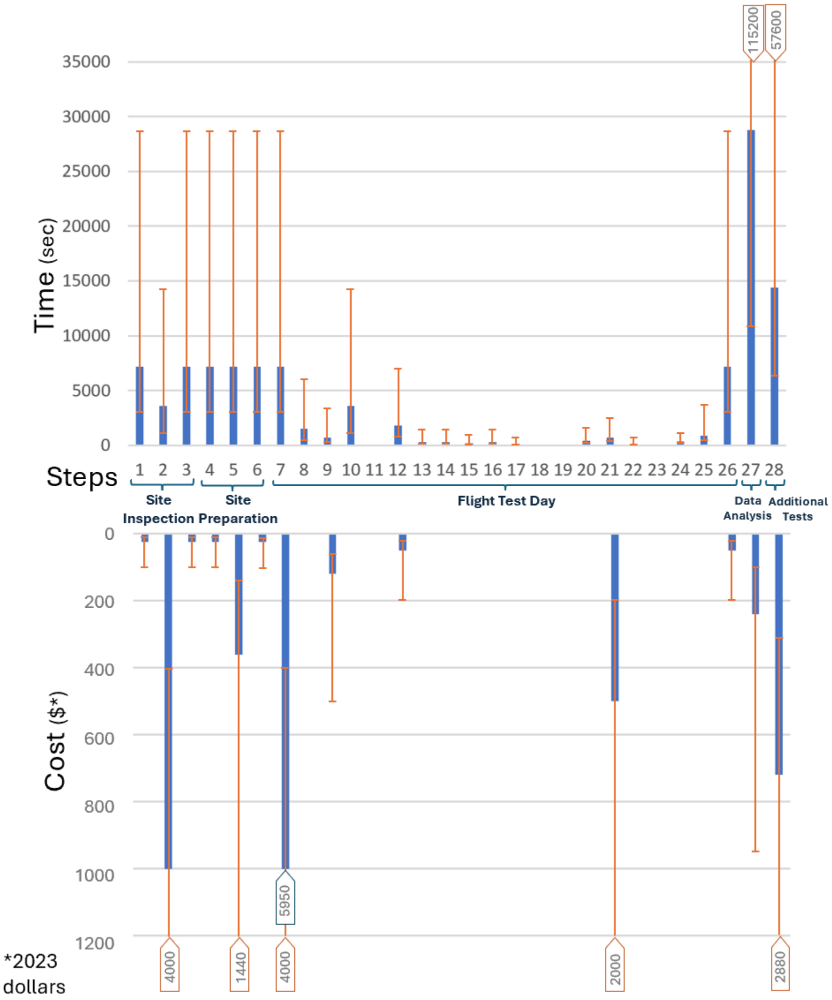


Figure 42. Time and cost estimates related to each noise testing phase and step.

As the model has been significantly expanded, the DoE is now conducted on all the steps of the process to enable a full analysis of the results and a comprehensive evaluation of testing alternatives. Furthermore, this approach allows us to explore a wide range of variables and assess their impact on the total time and cost of the noise testing process.
The inputs (i.e., individual times and costs) are now varied by multiplying the values by factors between [0.4, 4]. Figure 42 depicts the allocated time and cost to each step of the process with the hairline indicating the range of variation.
The baseline cost values have been estimated based on the list of equipment that has been used during the Causey Airport noise testing campaign. This served as a crucial starting point to formulate a more comprehensive list of equipment (Table 5) for which the prices have been either estimated or looked up online. The costs have been divided into two categories: (1) fixed costs consisting of all pieces of equipment, travel expenses, and rentals; and (2) variable costs such as the battery replacements for UAS or the personnel payment that depend on the duration of testing and/or the number of personnel. To generate this DoE, the Latin Hypercube Sampling (LHS) has been selected as the space-filling method of choice. Each process simulation has been conducted for the 10,000 DoE cases such that each case is repeated for 10,000 Monte Carlo runs.

The number of personnel available during each phase of testing can highly impact the time required to conduct certain tasks and eventually the total time of testing. Figure 43 showcases an example of the impact of the number of microphones and the number of personnel on the time needed to install the microphones. It has been assumed that one individual can install a single microphone in 5 min, and that one individual is always on standby as they could be carrying out a different task in parallel or supervising the installation process. In Figure 44, to help with the visualization of this plot, it has been broken down into two different plots such that the left plot displays the change in time with respect to the number of personnel for the installation of 10 microphones and the right plot shows the change in time with respect to the number of microphones for a total of six personnel members. For example, considering a total of 10 microphones and six personnel members are on site, only five members can participate in the installation process. The installation team would simultaneously install one microphone each then install the remaining five microphones, which requires a total duration of 10 min.

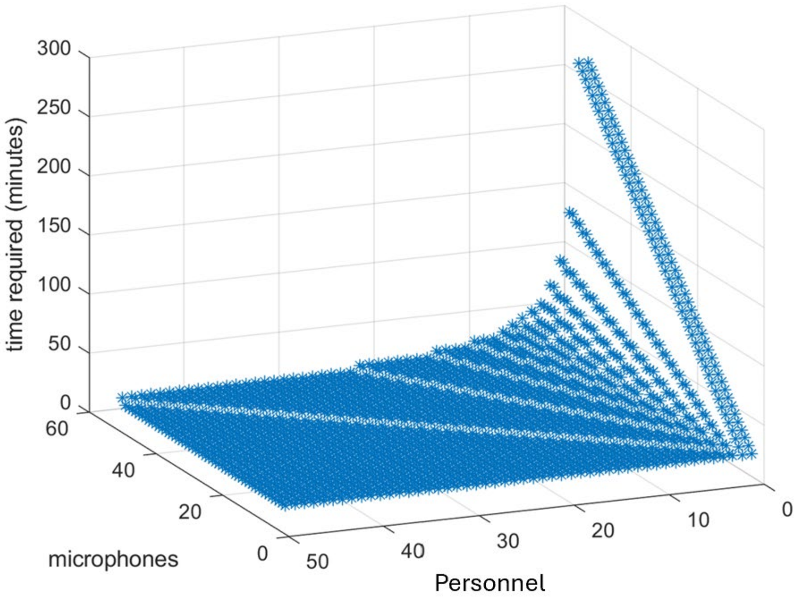


Figure 43. Three-dimensional plot of the impact of number of microphones and personnel variations on microphone installation time.

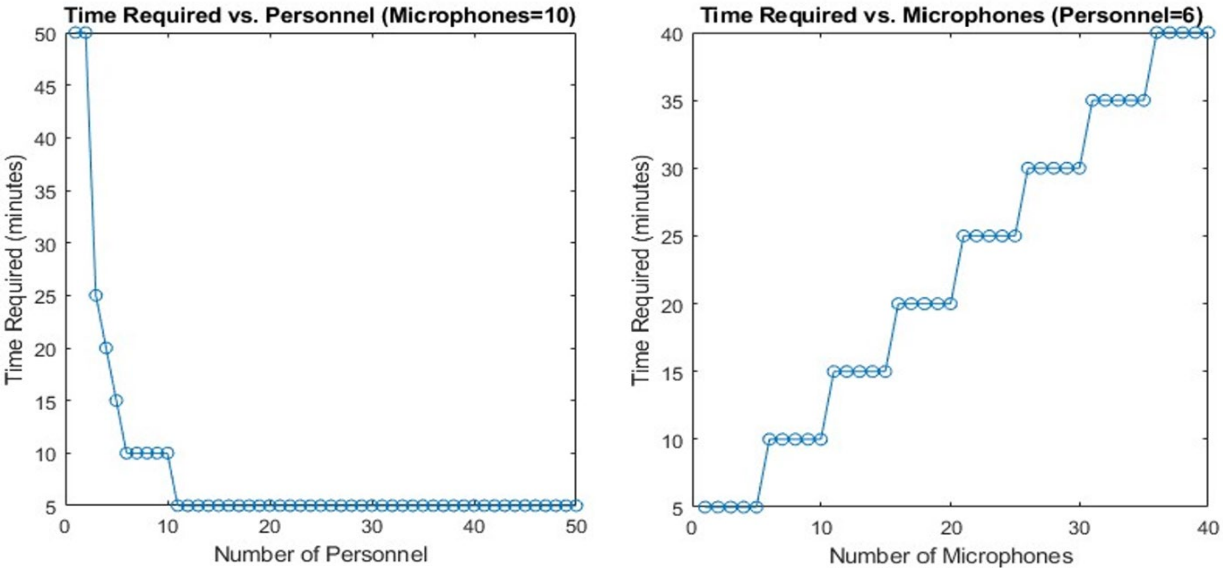


Figure 44. Two-dimensional projects of the impact of number of personnel on installation time of 10 microphones (left) and the impact of the number of microphones on equipment installation time for a team of six personnel (right).

The baseline process for the PIM exclusively considers a hover flight profile with three test points with a minimum of six runs per test point. Each test point refers to a test condition with a specific combination of weight, speed, and altitude. With the use of only one microphone, UASs will fly at three different locations relative to that microphone (Figure 45). The analysis is turned into a parametric analysis capable of automatically changing the types of flight profiles and number of test points based on a set of user-defined inputs without having to manually modify the values in the input files. This enables the modeling of any combination of flight procedures, thus capturing noise testing campaigns of any desired size. Other user-defined inputs apply to parameters that would simultaneously affect multiple steps of the process in different ways, such as the number of staff members, number of microphones, travel duration to the test site, etc. Manually assessing and incorporating the changes due to variation in these parameters can be very tedious, as many steps can be directly or indirectly affected. Thus, all the impacted steps are identified beforehand, and the effects are quantified and mathematically modeled in terms of time and cost consequences. Once the user identifies any combination of parameters, the code will automatically implement the corresponding changes to the time and cost values in the input file of the baseline process.

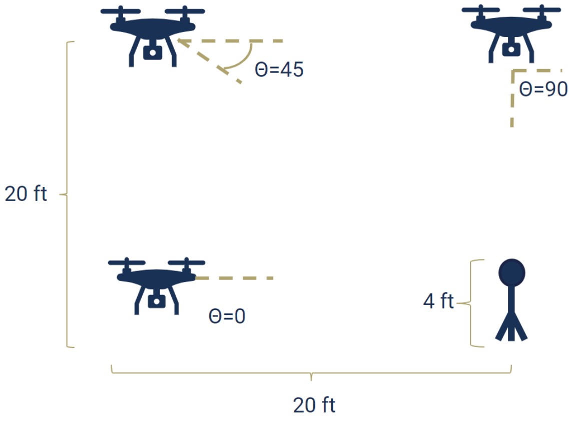


Figure 45. Baseline noise testing process (hover flight profile).

Calibration is an essential step for ensuring model accuracy and the validity of results and findings. This task requires a completed process simulation capability, which will be calibrated against a baseline that captures current certification testing plans and processing steps. The pivot to the UAS category has included plans to interface with ASCENT partners who can provide testing plans and noise datasets to be used as calibration data and overall process information. This task will be one of the key focus topics for the ASCENT Project 061 Year 3 activities. Scalability issues are bound to arise as this model is expanded to reflect the full verification thread; thus, the next step is to discuss options for data that ASCENT Project 061 partners could provide for further calibrating the model, according to the use cases of preference.

Task 4.4 Develop a Proof-of-Concept Demonstration of the PIM Capabilities

In a proof-of-concept demonstration of the complete certification process simulation capability within the PIM, the ASCENT Project 061 team has been formulating use case examples based on scenarios provided by OEM partners. For these examples, simulation runs are being executed to test modifications and proposed improvements over the baseline process. Under this task, a first demonstration of the PIM has been completed. For this example, the goal is to assess the impact of a simplified noise collection/analysis process for the Waco Aircraft® YMF-5 propeller aircraft.

The baseline (original) process was formulated within the PIM and executed using the best estimates for time and cost. The term "best" implies that our team had to rely on rationalized assumptions that were initially formulated by input from OEM partners. As this information could be of a sensitive nature for most OEMs, guidance was provided at a higher level, without any limitations on how the information would be distributed. Hence, for this example, a simplified process for flight segment testing is proposed, where a certain calculation is removed from the standard process. As shown in Figure 45, the simplified process removes step 18, the calculation of the second flight segment, while other steps were updated with new values to capture the updated process.

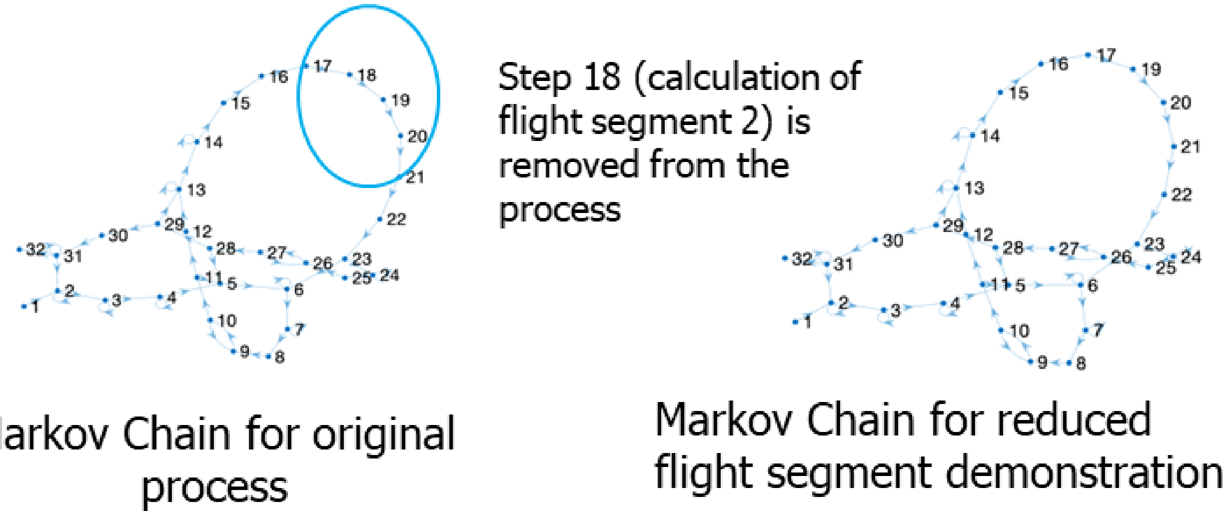


Figure 46. Process modification with step 18, the calculation of the second flight segment, is removed from the Markov chain flight-testing process.

A comparison of the two process alternatives is presented in Table 6. The results were obtained from an MCMC analysis and comparison between the baseline and simplified process. The PIM was able to quantify measurable savings in time and cost. In particular, the average process cost shows a reduction of 16%, and the average process time shows a decrease of 2%. The results are highlighted in Figure 47, where the Monte Carlo simulation data are plotted as distributions for the cost and time required for the process.

® Waco Aircraft is a registered trademark of Dimor Group Inc., Battlecreek, Michigan.

Table 6. Summary of cost ($) and time (hr) improvements.

		Mean
Original	**Cost($)**	166,770
	Time(hr)	155
Reduced Segments	**Cost($)**	140,430
	Time(hr)	151

With this fundamental example showcased under this task, the groundwork is set for scaling up the PIM to more comprehensive modifications, which would also include technology impact forecasting functions. As this practice will now be exclusive to the UAS category, the ASCENT Project 061 team's priorities are to investigate current noise testing plans and procedures and to be able to propose promising equivalent procedures.

Case Study 1

The FAA's Notice of Proposed Rulemaking (NPRM) for the Matternet Model M2 Aircraft (FAA, 2022a) outlines the use of a single microphone mounted on a tripod or pole, positioned 4 ft above the ground, for unmanned aircraft (UA) noise certification measurements. This proposed rule aims to streamline the process and reduce costs and workload by utilizing a single microphone. However, the possibility of using multiple microphones for hover noise testing was also explored to shorten testing time and enhance efficiency. Notably, the FAA is open to reviewing and approving multiple microphone configurations if deemed beneficial by the applicant. Consequently, a model-based approach is necessary to comprehensively evaluate and select between the proposed single-microphone setup and the alternative multiple-microphone configuration.

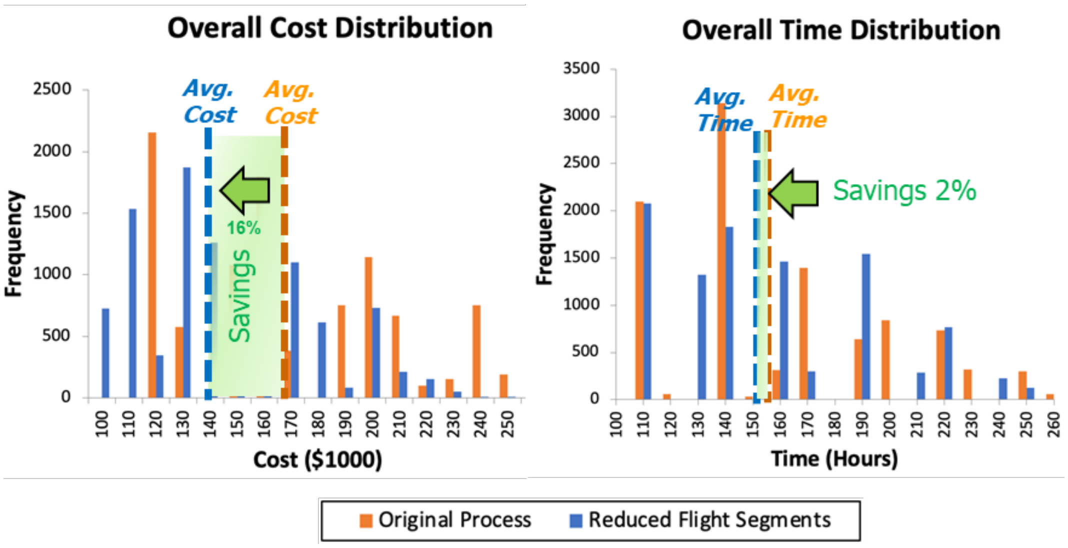


Figure 47. Execution of Markov-chain-based Monte Carlo analysis and comparison between the baseline and simplified process.

Following the adoption of rule for applicability for the Matternet M2 aircraft, the FAA introduced subsequent noise certification standards for other models, including the Flytrex FTX-M600P. In this section, the PIM capabilities are utilized to compare the single-microphone configuration (baseline process) with the multiple-microphone configuration (alternative process) for a UA hover test, using the Flytrex FTX-M600P aircraft as a case study. According to the hover test conditions specified in paragraph 16, subparagraphs (b) through (e) of the Flytrex noise certification standards (FAA, 2023), the baseline configuration involves the aircraft hovering at three distinct spatial locations relative to the single microphone, as depicted in **Error! Reference source not found.**. Conversely, the alternative configuration uses three microphones, requiring the aircraft to hover at a single spatial location relative to these microphones, as shown in **Error! Reference source not found.**. A representation of the Markov Chain for both the baseline and alternative processes is provided in Figure 50.

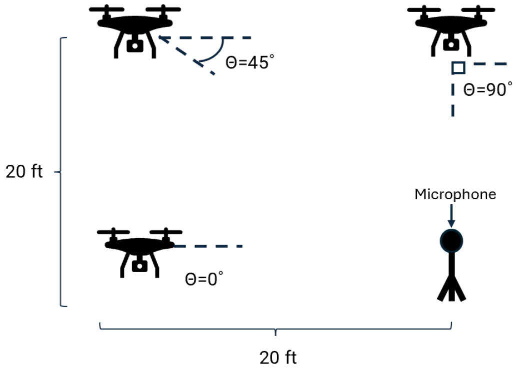


Figure 48. Microphone layout for the baseline process during the hover measurements.

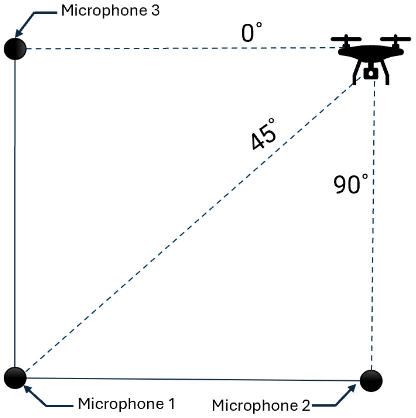
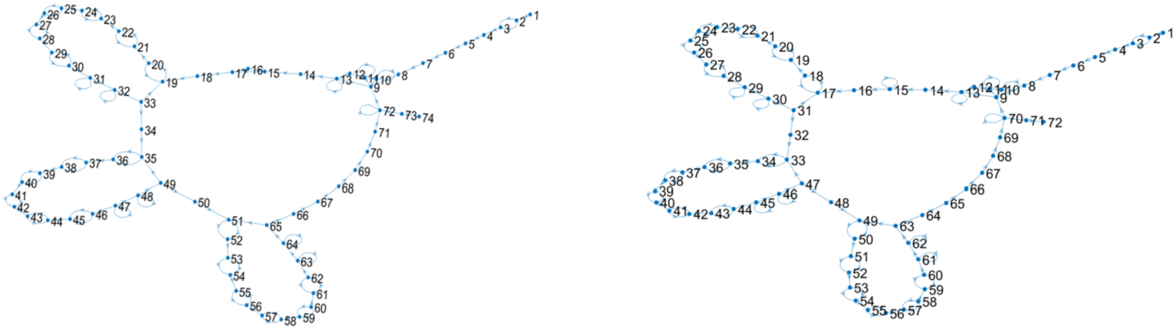


Figure 49. Microphone layout for the alternative process during the hover measurements.


Baseline Process
(74 steps)

Alternative Process with 3 Merged Steps
(72 steps)

Figure 50. Markov Chain representation for the baseline process (left) and alternative process (right).

As outlined in the case study setup, a DoE consisting of 2,000 cases, each with 10,000 Monte Carlo simulations, was conducted. Process simulations for both the baseline and alternative configurations were performed to create a parametric, interactive decision-making environment. This environment enables the comprehensive comparison of test processes using various visualization techniques, including operational viewpoints, histogram overlays, and sensitivity analysis plots. This section provides an analysis of the process simulations for the baseline and alternative configurations for the Flytrex FTX-M600P case study, accompanied by visualizations to support interpretation of the results.

The operational viewpoint of the case study setup, shown in Figure 51, combines the schematic diagrams, providing a more realistic and comprehensive visual representation of the test setup. Following this, process simulations for both the baseline and alternative configurations were performed, producing key output metrics, specifically mean time and mean cost, for each case in the DoE. Histogram overlays were used to visually compare the two processes in terms of time and cost, as seen in **Error! Reference source not found.** and **Error! Reference source not found.**. These figures demonstrate that the baseline process results in both lower mean time and mean cost compared to the alternative process. The higher cost of the alternative process is expected due to the additional microphones, which incur extra costs for equipment, installation, and calibration.

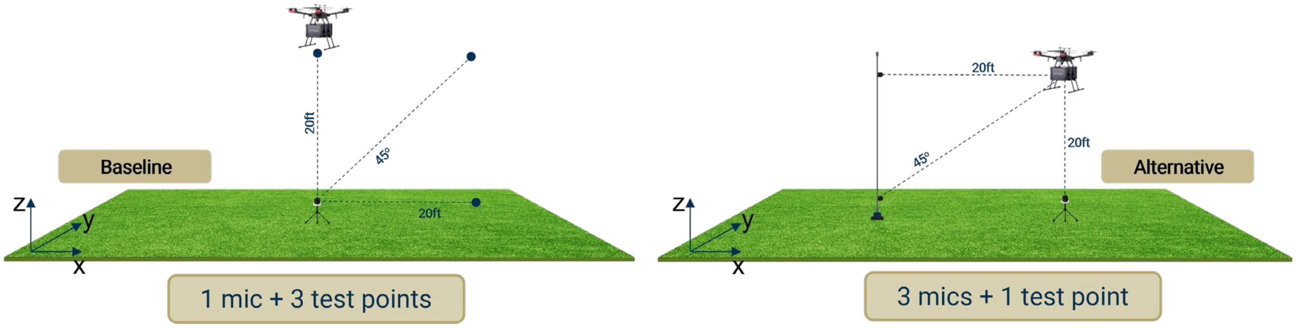


Figure 51. Operational viewpoint of baseline vs. alternative test set up for Flytrex FTX-M600P.

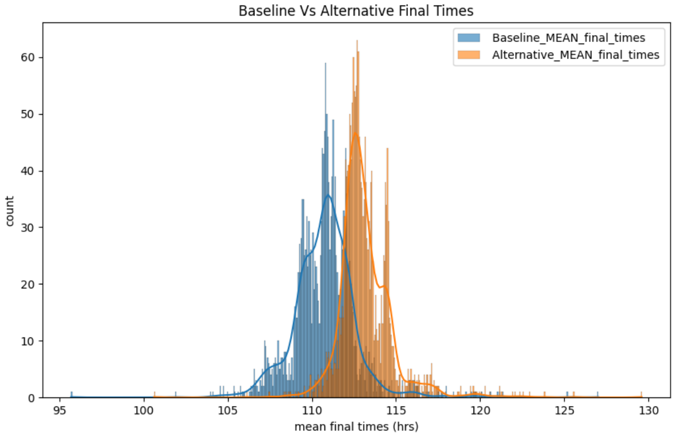


Figure 52. Baseline vs. alternative mean final times overlay.

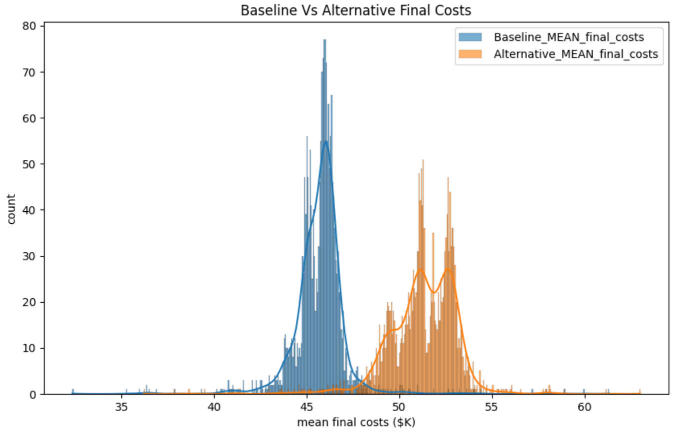


Figure 53. Baseline vs. alternative mean final costs overlay.

The time metric, however, exhibits more variability and is influenced by factors such as calibration time and the likelihood of test failures. Under the specific parameter values used in the model, the baseline process results in a shorter mean time. This indicates that the additional time required for microphone installation and calibration in the alternative process outweighs the time lost due to potential test failures. However, if the probability of test failure and the calibration time for a single microphone were increased, there could be cases where the alternative process proves more time efficient. In such cases, the single microphone in the baseline process would require repeated setup and calibration at various test points, extending the total test duration.

Histogram overlays provide a useful means of comparing baseline and alternative processes by visualizing the mean distributions of PIM outputs, such as time and cost. However, histogram overlays do not capture the variability of these metrics in relation to input parameters across different steps in the noise testing process. Understanding this variability is crucial for assessing a testing process's robustness to uncertainties. Tools like the JMP Prediction Profiler offer dynamic visualization capabilities, displaying relationships between input predictors (e.g., time or cost for specific testing steps) and output metrics. To enable interactive decision making, meta or surrogate models are needed to map input parameters to PIM outputs. However, the non-normal distribution observed in the Monte Carlo simulations necessitated the evaluation of various probability density functions (PDF) to replicate the data accurately. Among these, the log-normal distribution proved most suitable, demonstrating the closest match with minimal error, as shown in **Error! Reference source not**

found., and further validated by reconstructing the Monte Carlo distribution using random samples within the parameters of the log-normal PDF (i.e., μ, σ, and scale), as depicted in **Error! Reference source not found.**.

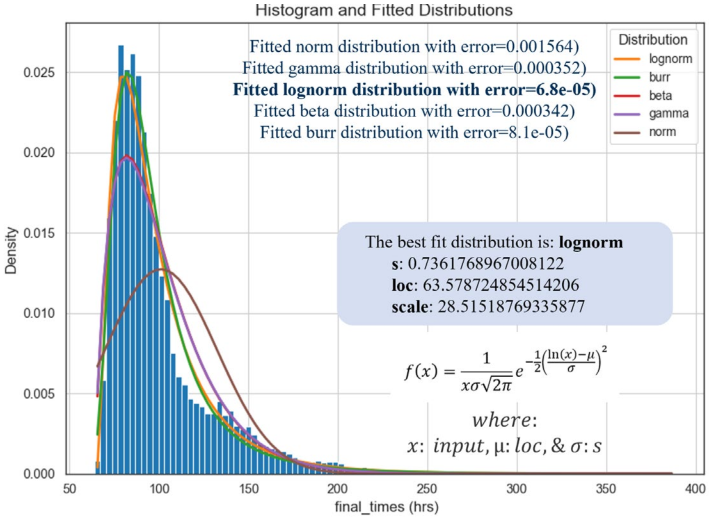


Figure 54. Sample Monte Carlo distribution of a single DoE case.

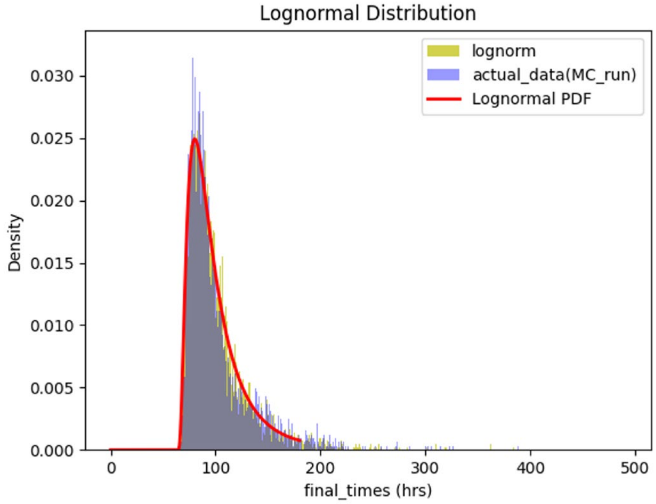


Figure 55. Actual vs. predicted Monte Carlo distribution fit using log-normal probability density functions (PDF).

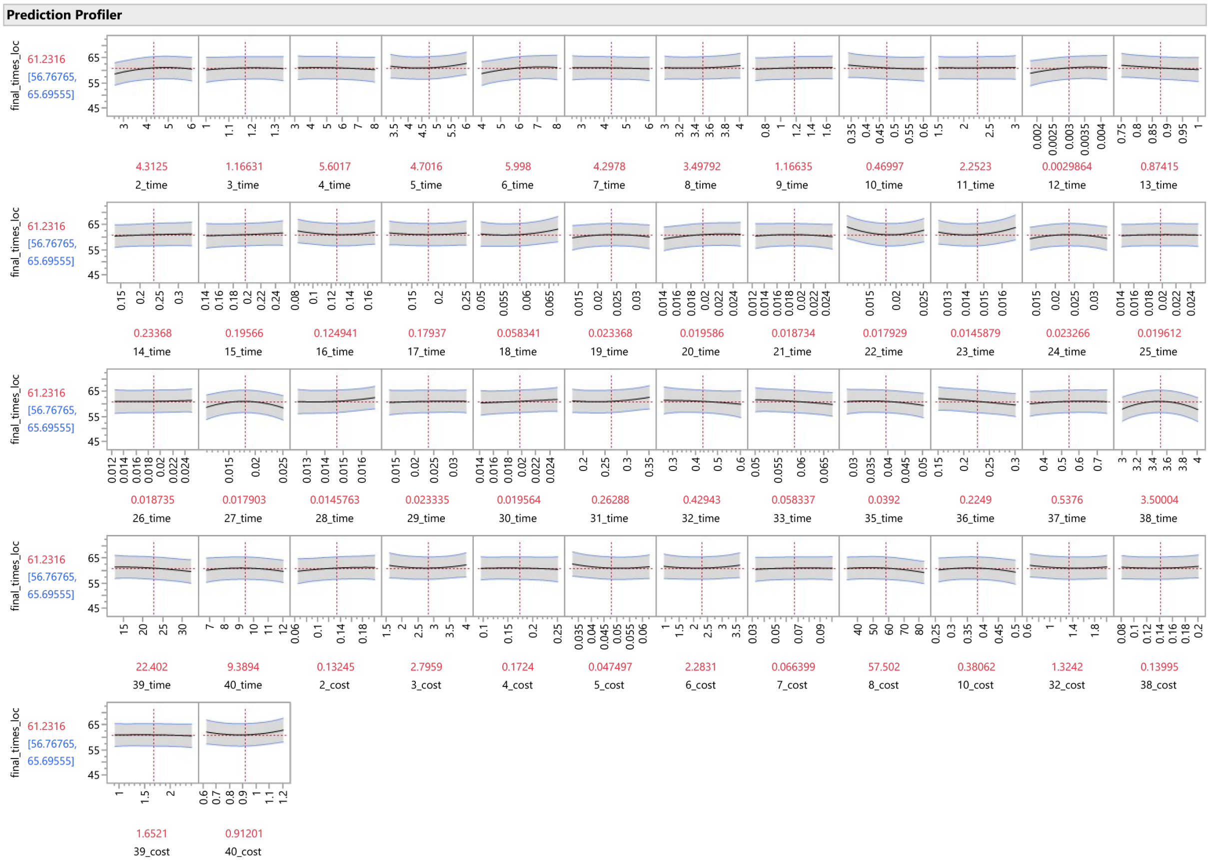
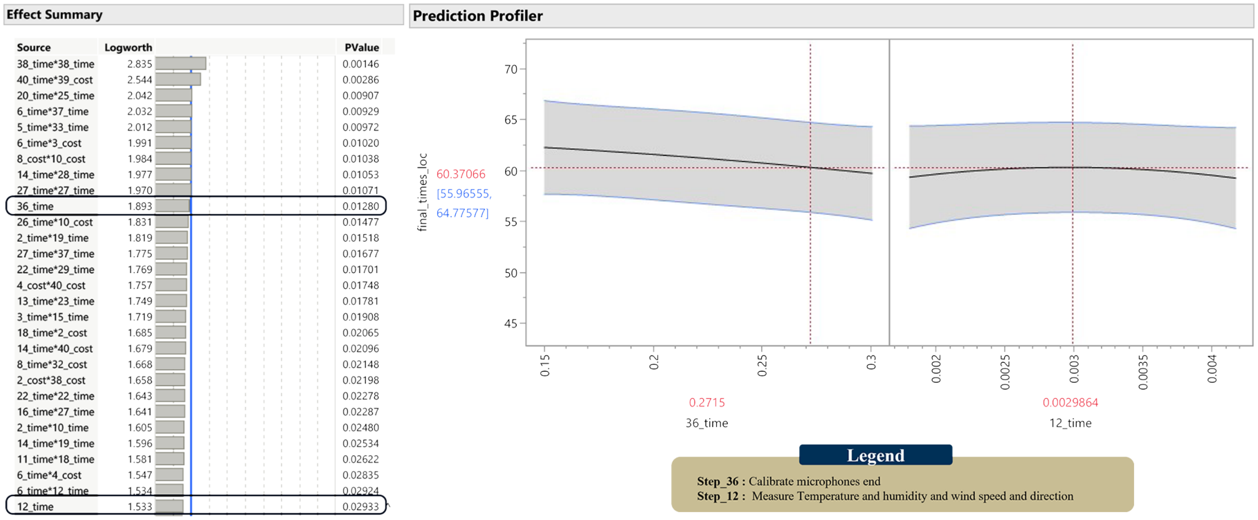


Figure 56. Prediction profiler plot of alternative process time generated using the JMP Prediction Profiler.

Using the log-normal PDF, calculations were performed for each case in the DoEs. The resulting parameters of the log-normal PDF served as output metrics and were instrumental in developing surrogate models. For instance, focusing on the μ (location) parameter for the time associated with the alternative process, Prediction Profiler plots were generated (Figure 56) to evaluate the sensitivity of this output metric to the time allocated for each step in the testing process. Analysis of the predictor variables within the model revealed that steps 36 and 12 were statistically significant in predicting the location parameter, prompting a deeper investigation into their influence. This analysis, illustrated in Figure 57, shows the impact of holding step 12 constant while varying the time for step 36. The results reveal a significant correlation, including a directional change, emphasizing the importance of these steps in influencing variability. While this study primarily examines the location parameter for time in the alternative process, similar insights can be extended to other parameters and metrics for both baseline and alternative processes.



Effect Summary

Source	Logworth	PValue
38_time*38_time	2.835	0.00146
40_time*39_cost	2.544	0.00286
20_time*25_time	2.042	0.00907
6_time*37_time	2.032	0.00929
5_time*33_time	2.012	0.00972
6_time*3_cost	1.991	0.01020
8_cost*10_cost	1.984	0.01038
14_time*28_time	1.977	0.01053
27_time*27_time	1.970	0.01071
36_time	1.893	0.01280
26_time*10_cost	1.831	0.01477
2_time*19_time	1.819	0.01518
27_time*37_time	1.775	0.01677
22_time*29_time	1.769	0.01701
4_cost*40_cost	1.757	0.01748
13_time*23_time	1.749	0.01781
3_time*15_time	1.719	0.01908
18_time*2_cost	1.685	0.02065
14_time*40_cost	1.679	0.02096
8_time*32_cost	1.668	0.02148
2_cost*38_cost	1.658	0.02198
22_time*22_time	1.643	0.02278
16_time*27_time	1.641	0.02287
2_time*10_time	1.605	0.02480
14_time*19_time	1.596	0.02534
11_time*18_time	1.581	0.02622
6_time*4_cost	1.547	0.02835
6_time*12_time	1.534	0.02924
12_time	1.533	0.02933

Prediction Profiler

Step_36 : Calibrate microphones end
Step_12 : Measure Temperature and humidity and wind speed and direction

Figure 57. Key steps sensitivity plot generated using the JMP Prediction Profiler.

Case Study 2

The International Organization for Standardization provides detailed methodologies for measuring sound pressure levels in its ISO 3744 standard (ISO, 2010), which outlines microphone positioning, test point selection, and the number of test runs required for various flight profiles. Additionally, ISO 5305 (ISO, 2024) specifies configurations and microphone layouts for testing UASs in anechoic chambers or wind tunnels. EASA adopts a proportional, risk-based framework for UAS operations, classifying them into three categories: (1) open, (2) specific, and (3) certified. The EASA category, applicable to UAS with a maximum takeoff mass (MTOM) up to 600 kg (1323 lb), includes guidelines for noise emission assessments. EASA has also proposed noise assessment standards for air taxis under the EPTS, covering VTOL aircraft with tilting and nontilting rotors.

This section presents and analyzes results from the PIM for the second case study, which evaluates various testing procedures defined by existing standards and guidelines for UA and VTOL aircraft. To align with these regulatory standards, three models were developed for noise testing across different vehicle categories: (1) low risk indoor testing (UAS with MTOM ≤ 25 kg), (2) medium risk outdoor testing (25 kg < MTOM ≤ 600 kg), and (3) high risk outdoor testing (VTOL with 600 kg < MTOM ≤ 80,000 kg). The high-risk model for outdoor testing specifically addresses VTOL aircraft with tilting rotors. Table 7 summarizes the testing procedures from these guidelines, forming the basis for creating simulations to replicate certification noise testing and outlining the corresponding test runs for each category. To enable sensitivity analysis and account for cost and time uncertainties, the DoE excludes travel-related process steps, as their extended durations could disproportionately influence results. Only unique process steps are included as variables, with repetitive tasks represented by a single instance.

Table 7. Testing procedures set by existing standards and guidelines for UA and VTOL aircraft. EASA: European Union Aviation Safety Agency, ISO: International Organization for Standardization, MLW: maximum landing weight, MTOW: maximum takeoff weight, UAS: unmanned aircraft system, VTOL: vertical takeoff and landing.

Procedure Type	ISO 3744 (UAS ≤ 25kg)	EASA (UAS ≤ 600kg)	EASA (VTOL ≤ 80000kg)
Risk Level	Low Risk	Medium Risk	High Risk
Testing Type	Indoor Testing	Outdoor Testing	Outdoor Testing
Flight Profiles	Hover	Flyover - Hover	Takeoff - Approach - Hover - Flyover
Test Points	1 MTOW (hover)	1 MTOW + 1 ETOW (hover)	1 MTOW (takeoff) 1 MLW (approach) 1 MTOW (hover) 3 MTOW (flyover)
Test Runs	3 runs/test point	6 runs/test point	6 runs/test point
# of Microphones	10	1	9 total: 3 (takeoff- approach - flyover) 9 (hover)

The low-risk category indoor testing involves fewer tasks (27 steps yielding 32 variables, with 16 time and 16 cost variables) compared to outdoor procedures for medium-risk (146 steps yielding 44 variables) and high-risk (116 steps yielding 44 variables) categories. Notably, the medium risk outdoor testing procedure has slightly more steps due to the requirement to conduct tests at both maximum and empty takeoff mass, as outlined in Table 7.

A DoE with 10,000 cases was constructed, each case undergoing 10,000 Monte Carlo runs to account for the inherent variability in the simulation. The PIM was used to calculate the mean final time and cost for the testing procedures across all cases. Histograms of these outputs for the three categories are shown in **Error! Reference source not found.** and **Error! Reference source not found.**. From the overlay of mean final times, it is evident that low-risk indoor testing requires the least time due to its controlled environment and reduced uncertainties. Interestingly, while medium-risk outdoor testing includes more steps and variables than high-risk outdoor testing, the latter exhibits slightly longer mean final times across the DoE cases.

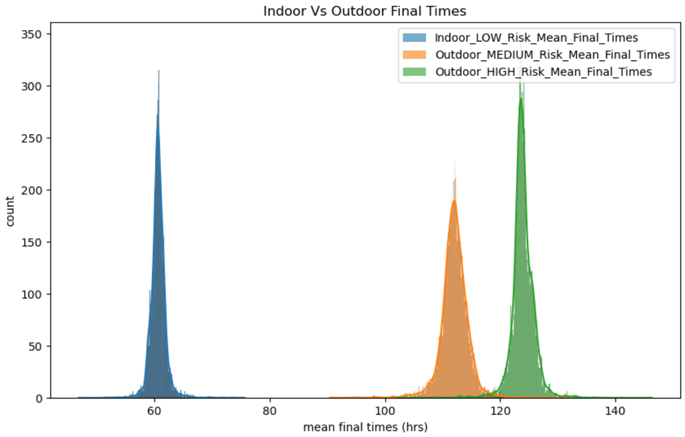


Figure 58. Indoor vs. outdoor testing final times overlay.

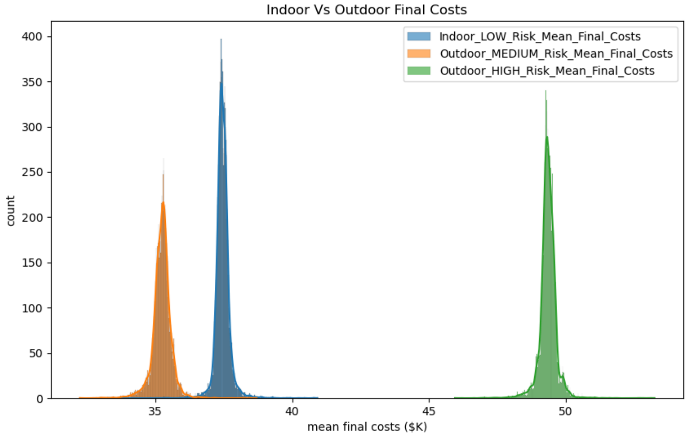


Figure 59. Indoor vs. outdoor testing final costs overlay.

In terms of costs, high-risk outdoor testing is the most expensive, driven by the need for nine microphones and multiple flight test profiles and test points. Surprisingly, medium-risk outdoor testing incurs slightly lower costs than low-risk indoor testing. This unexpected result is primarily due to the number of microphones utilized during each testing procedure.

Analyzing the complexity metrics of the three testing alternatives discussed earlier and applying the metrics outlined in Task 4.2 reveals that the low-risk indoor testing procedure consistently achieves the lowest scores across all metrics. This indicates it is the most efficient and least uncertain approach. The high-risk outdoor testing procedure ranks second, while the medium-risk outdoor testing procedure has the highest scores, making it the least efficient and most uncertain. Table 8 below summarizes the calculated complexity scores for each testing category.

Table 8. Process complexity scores of testing procedures.

Testing Procedure Type	Low Risk (ISO 3744)	Medium Risk (EASA)	High Risk (EASA)
# of Steps (N)	27	146	116
Cyclomatic Complexity	0.2321	0.2823	0.2735
Control Flow Complexity	0.2839	0.363	0.3534
Process Entropy	0.1441	0.2837	0.2732
Decision Density	0.4074	0.5342	0.5172
Overall Complexity	**0.1489**	**0.3336**	**0.3068**

Table 9 presents the overall time, cost, and complexity scores for the three testing procedures discussed, highlighting the relative difficulty of certification for each category. The low-risk indoor testing procedure stands out with the lowest overall time and complexity, making it the easiest option for certification. In contrast, the high-risk outdoor testing procedure has the highest time and cost, making certification more challenging.

Table 9. Overall time, cost and complexity of testing procedures.

	Low Risk (ISO3744)	Medium Risk (EASA)	High Risk (EASA)
Overall Time	60h 38min	112h 05min	123h 56min
Overall Cost	$37,459.83	$35,236.86	$49,353.97
Overall Complexity	0.1489	0.3336	0.3068

Lowest certification burden

Highest certification burden

Further Model Implementations
The earlier case studies demonstrated the ability of the Process Evaluation Model to evaluate and quantify the certification burden of various noise testing procedures, as defined by different regulatory standards, in terms of time, cost, complexity, and risks of schedule or budget overruns. In contrast, the next section explores the time and cost impacts of performing the same noise testing procedure under varying conditions. This analysis supports improved planning and resource management, including decisions regarding equipment, personnel, and test location selection. To illustrate the advantages of this capability, three use cases were developed, simulated, and analyzed.

(1) Alternative Testing Location and Weather Effects
Noise testing may be conducted at various locations, with the optimal test site depending on factors such as proximity, site area, ground type, background noise, and weather conditions. These factors significantly impact testing duration, overall expenses, measurement quality, and the likelihood of requiring an additional day to repeat measurements. This use case compares two noise testing processes under different travel distances and weather conditions:

- **Baseline Process**: The test site is 2 hr away, with stable weather expected.
- **Alternative Process**: The test site is 40 min away, but weather conditions are less stable, with a higher likelihood of rain and strong winds.

While the alternative process reduces travel time and expenses, it increases the probability of adverse weather, leading to higher chances of test run rejections and additional test days for measurement repetitions. This presents a trade-off between travel-related time and costs and those associated with weather-impacted noise measurements.

To model these scenarios, travel time and costs, along with weather-related probabilities, were adjusted, and each process was simulated using 10,000 Monte Carlo runs to account for the inherent uncertainty. Table 10 summarizes the mean time and cost results, while Figure 60 and Figure 61 visualize the total time and cost distributions for each process, displaying a sample of 50 Monte Carlo runs for clarity. The results show that the alternative process incurs higher costs and nearly doubles the testing duration, indicating that shifting to a closer location with unstable weather is not advisable for this scenario.

Table 10. Mean time and mean cost (across 10,000 Monte Carlo runs) of the baseline process vs. the alternative process.

	Baseline process	Alternative Process
Average Time (h)	45.655	90.781
Average Cost ($)	18602.542	34600.877

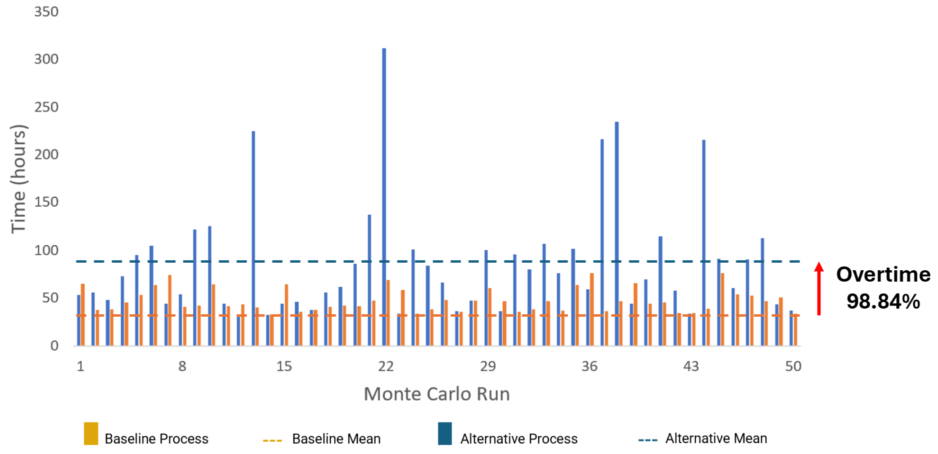


Figure 60. Total time (sample of 50 Monte Carlo runs) and mean time (10,000 Monte Carlo runs) between the baseline and alternative processes.

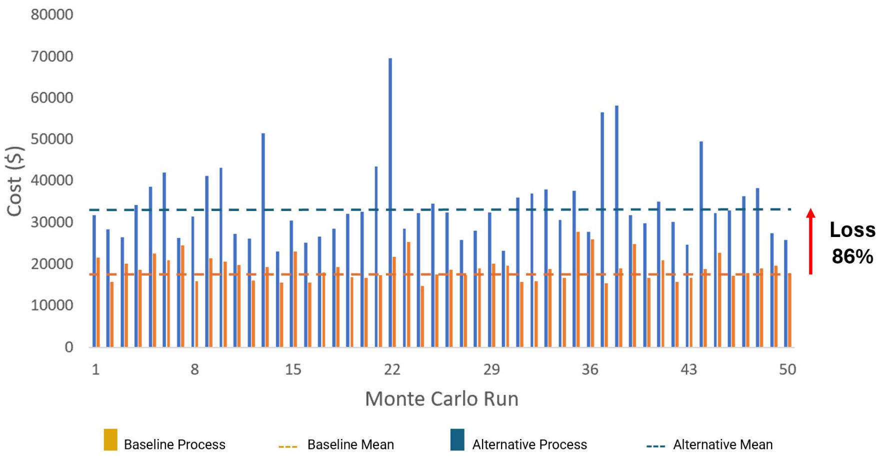


Figure 61. Total costs (sample of 50 Monte Carlo runs) and mean cost (10,000 Monte Carlo runs) of the baseline and alternative processes.

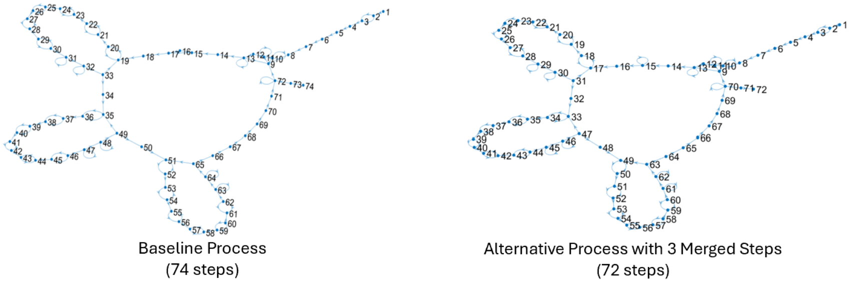
(2) Alternative Dispatching and Sequencing of Tasks

Parallel processing enables multiple tasks to be executed simultaneously, leading to a significant reduction in the overall noise testing time. This use case evaluates the impact of parallel processing by comparing two testing approaches:

- **Baseline Process**: All tasks are performed sequentially.
- **Alternative Process**: While some tasks depend on others and cannot be performed in parallel, and others involve uncertainty requiring separate handling to maintain accuracy, three specific tasks— (1) synchronizing data acquisition clocks, (2) calibrating microphones, and (3) installing windscreens—are executed simultaneously.

Figure 62 illustrates the Markov Chain representations of the baseline process, which includes 74 steps, and the alternative process, which reduces the total steps to 72 by merging three tasks for parallel execution. Table 11 outlines the mean time for each process, showing that the alternative process saves 2.25 hours, a 4.02% reduction in total testing time (as depicted in Figure 63).

This example demonstrates the potential for significant time savings through parallel task execution in noise testing, provided sufficient on-site personnel are available to optimize task allocation.


Baseline Process
(74 steps)

Alternative Process with 3 Merged Steps
(72 steps)

Figure 62. Markov Chain representation for the baseline process (left) and alternative process (right).

Table 11. Mean time (across 10000 Monte Carlo runs) of the baseline process vs. the alternative process.

	Baseline process	Alternative Process
Average Time (h)	55.798	53.554

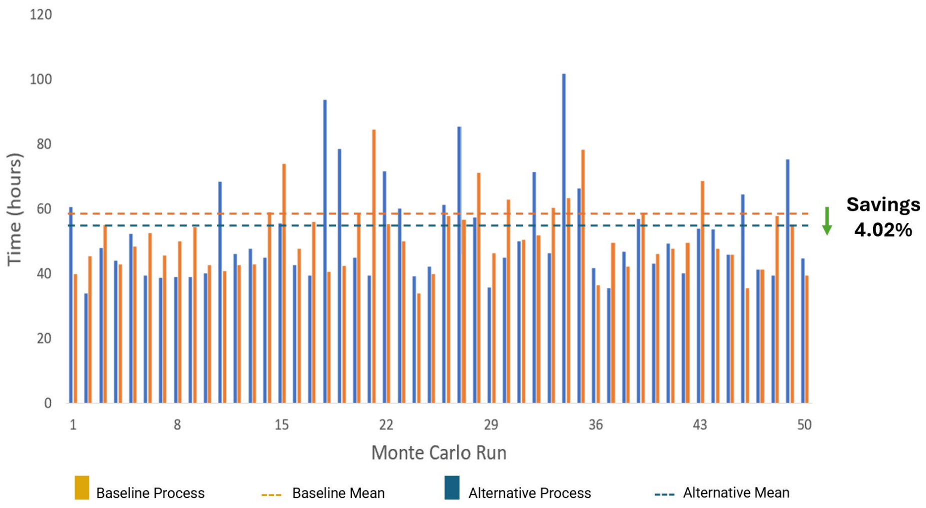


Figure 63. Total time (sample of 50 Monte Carlo runs) and mean time (10,000 Monte Carlo runs) of the baseline and alternative processes.

(3) Effects of Personnel Structure on Small Certification Testing vs. Large Testing Campaigns

Increasing the number of personnel may raise immediate payroll costs, but it can potentially shorten testing durations or enhance test quality, potentially reducing long-term expenses. This use case explores the effects of doubling the personnel assigned to each of the five phases of the noise testing process (Table 12). Two scenarios are modeled and analyzed: a standard noise certification process and a larger experimental noise testing campaign. The baseline personnel numbers are estimated for demonstration purposes, with user-defined inputs that the model adjusts automatically.

Table 12. Mean time (across 10,000 Monte Carlo runs) of the baseline process vs. the alternative.

Noise Testing Phase	Baseline process: Number of Personnel	Alternative Process: Number of Personnel
Site Inspection	2	4
Site Preparation	1	2
Flight Test Day	3	6
Data Analysis	1	2
Additional Test Day	2	4

Increasing the number of personnel reduces the time needed for site inspection, preparation, and the installation and calibration of equipment. However, it also raises travel and payroll expenses. With a larger team, parallel task execution is enhanced, leading to more efficient resource utilization, though this also adds complexity to the process. In the baseline certification scenario, a single microphone is used, whereas the larger campaign involves 21 microphones. Expanding the team reduces time for site setup and equipment calibration but increases costs for travel, wages, and equipment, particularly if elevated setups (e.g., poles or cranes) are required.

The results show that doubling personnel reduces total testing time by 12.19%, saving 5.67 hours. However, total costs increase by 45.15% (see Table 13, Figure 64, and Figure 65). While the alternative process achieves time savings, the higher personnel costs outweigh the benefits of reduced work time.

Table 13. Mean time and mean cost (across 10000 Monte Carlo runs) of the baseline process vs. the alternative process.

	Baseline process: Certification Testing	Alternative Process: Certification Testing	Baseline process: Large Experimental Campaign	Alternative process: Large Experimental Campaign
Average Time (h)	45.655	40.092	55.798	44.591
Average Cost ($)	18,602.54	27,001.99	47,955.98	56,273.50

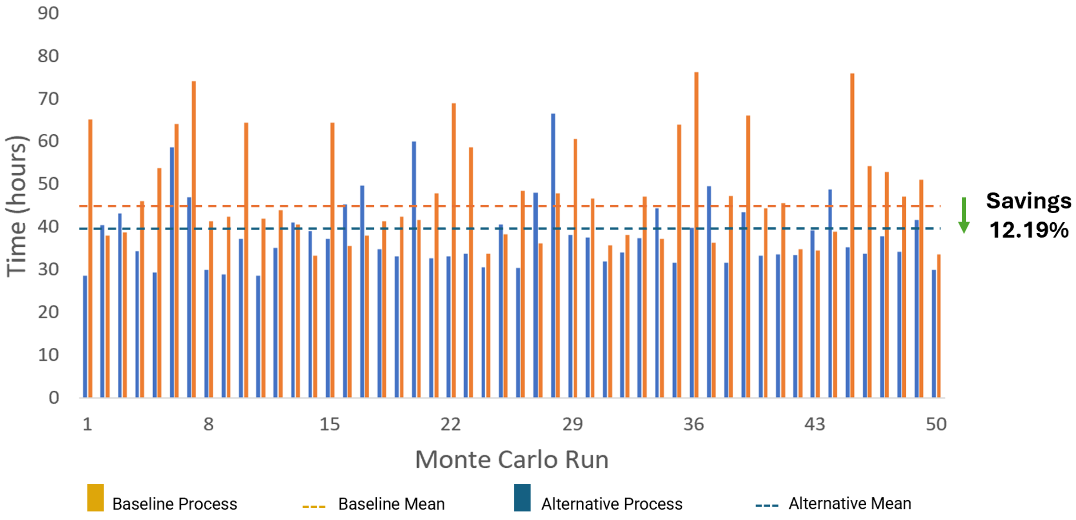


Figure 64. Total time (sample of 50 Monte Carlo runs) and mean time (10,000 Monte Carlo runs) between the baseline and alternative processes for certification testing.

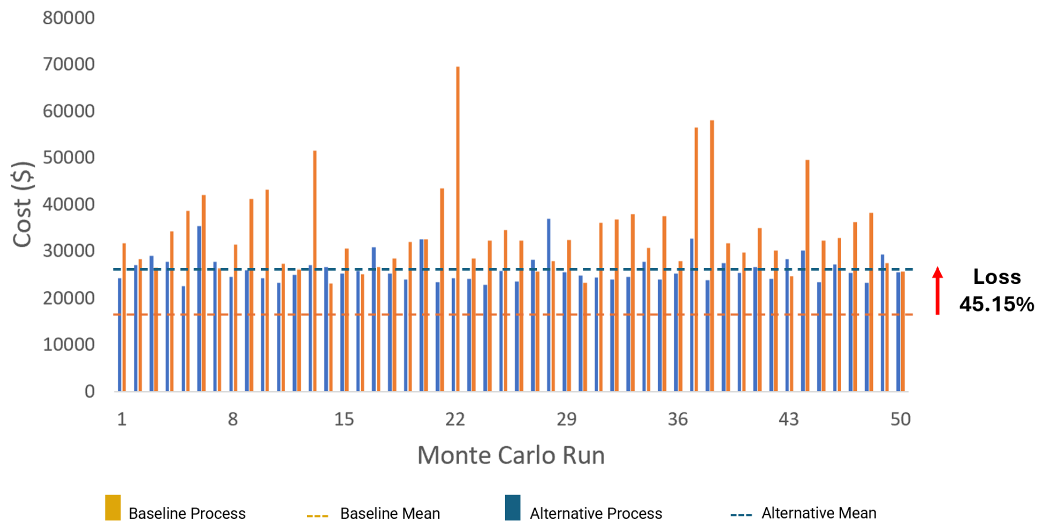


Figure 65. Total costs (sample of 50 Monte Carlo runs) and mean cost (10,000 Monte Carlo runs) of the baseline and alternative processes for certification testing.

Doubling the personnel team for a larger testing campaign results in a 20.09% reduction in time, significantly higher than the 4.02% savings observed for smaller certification testing (see Table 13 and Figure 66). Additionally, the financial loss is reduced to 17.34%, compared to 45.15% for certification testing (see Table 13 and Figure 67). The increased efficiency of additional personnel becomes more pronounced with the expansion of equipment, such as microphones, enabling more parallel task execution.

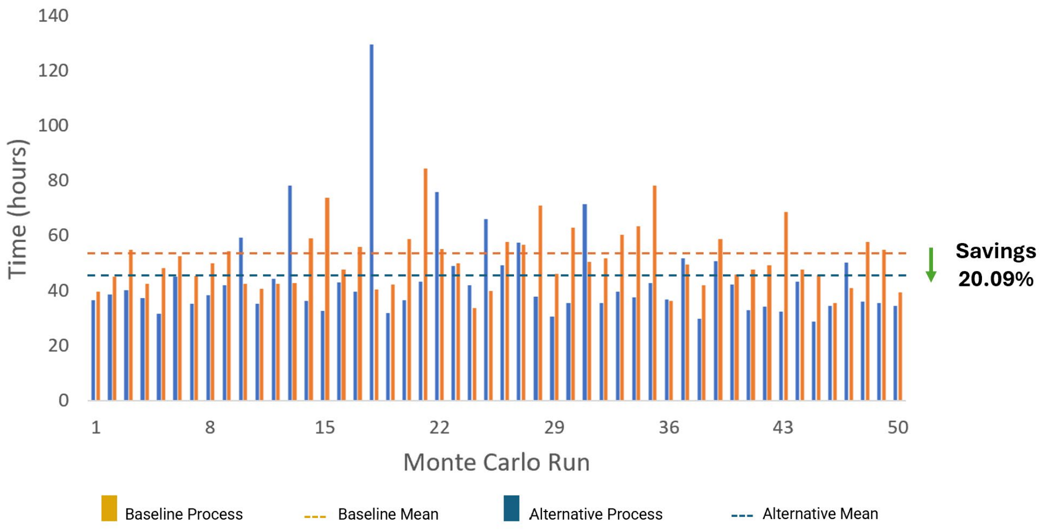


Figure 66. Total time (sample of 50 Monte Carlo runs) and mean time (10,000 Monte Carlo runs) between the baseline and alternative processes for experimental testing campaign.

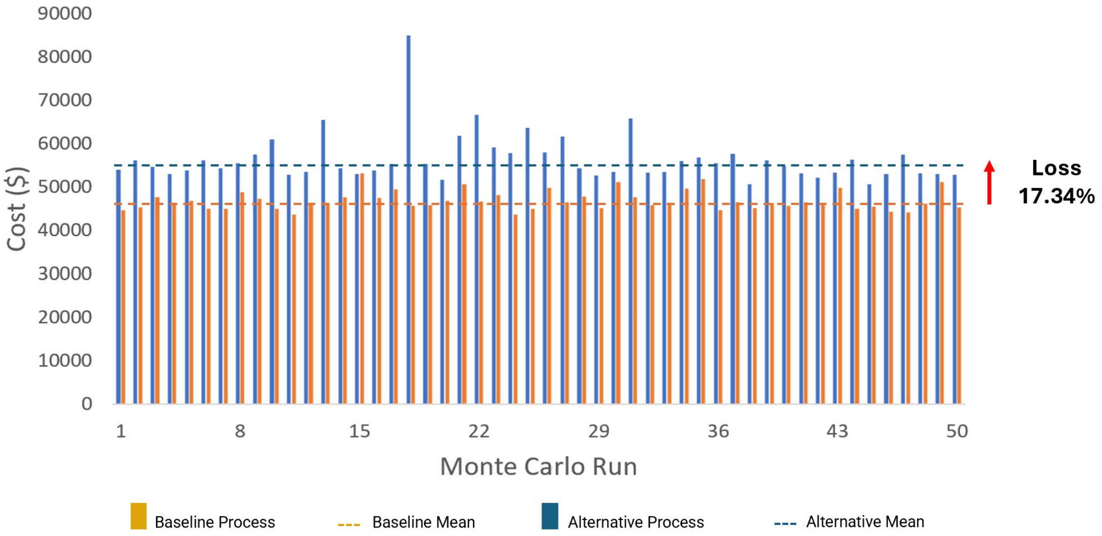


Figure 67. Total costs (sample of 50 Monte Carlo runs) and mean cost (10,000 Monte Carlo runs) of the baseline and alternative processes experimental testing campaign.

Milestones

Please refer to the milestones listed under Task 1.

Major Accomplishments

- Developed a small-scale PIM using DES as a deterministic modeling exercise.
- Developed a more comprehensive stochastic model using stochastic MCMC methods, formulated in a way that enables seamless integration into the verification thread within the MBSE framework.
- Defined a starting set of metrics as a working solution with a focus on process efficiency improvements.
- Designed approach for integrating the PIM with the verification model within the MBSE framework.
- Finalized PIM analysis workflow with the use of Monte Carlo simulation for Markov chain models of the certification testing process.
- Integrated workflow with the MBSE verification model.
- Obtained proof-of-concept use case for assessing the impact of process simplification through quantifiable outcomes, which has been supported by the current working version of the MCMC-enabled PIM module.
- Further improved and tuned the existing PIM with automation and parametrization of user-defined input data to make the model representative of any desired process.
- Applied the PIM to a typical plan for UAS noise testing to better capture the process and properly estimate the cost, staff, and time implications.

Publications

Published Conference Proceedings

Ali, H. E., Ravikanti, B., Balchanos, M. G., Harrison, E., & Mavris, D. (2025). MBSE Enabled Requirement Verification for a Traceable Regulatory Analysis Framework of UAS Noise Certification Standards. *AIAA SCITECH 2025 Forum* (p. 0367).

Mali, H., Geneti, N. F., Balchanos, M. G., Harrison, E., & Mavris, D. (2025). A Process Evaluation and Visualization Framework for Unmanned Aerial System (UAS) Noise Certification Testing. *AIAA SCITECH 2025 Forum* (p. 0368).

Balchanos, M., Ravikanti, B., Ali, H., Mali, H., D Harrison, E., & N Mavris, D. (2024, September 9-11). *A Regulatory Analysis and Process Improvement Decision Support Framework for Unmanned Aerial System (UAS) Noise Certification* [Conference presentation]. Quiet Drones 2024 Symposium, Manchester, United Kingdom.

Outreach Efforts

- Presented concepts to FAA and Volpe partners, who provided feedback on the tools and analysis methods.
- Participated in discussions with experts in the field with similar applications (i.e., process simulations for industrial systems, manufacturing, supply chains, etc.).

Awards

None.

Student Involvement

Although a small portion of the team has been leading the technical approach of PIM development, this task has involved the full team. Recent efforts to extend the PIM capabilities have been led by Hajar Mali, and the dashboard and visualization of results have been led by Nathnael Geneti.

Plans for Next Period

- Project ended on September 30, 2025.
- Publish peer-reviewed journal articles with *AIAA Journal* and AIAA SciTech.

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FAA. (2022). *Noise Certification Standards: Matternet Model M2 Aircraft.* Federal Aviation Administration. https://www.federalregister.gov/documents/2022/09/12/2022-19639/noise-certification-standards-matternet-model-m2-aircraft

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ASCENT Project 061 Year 5 Recap

The following key tasks and activities have been completed within the ASCENT Project 061 Year 5 performance period:

- Developed **a certification framework** to explore options for **standard setting** to support **noise certification of Emerging Technology Aircraft (ETA),**
- Demonstrated applicability of the current ASCENT Project 061 framework for noise certification of rotor or small propeller-driven UASs.
    - Formulated use cases that are aligned with needs and recommendations provided by OEM partners, with a focus on exploring implications of alternative testing procedures on regulatory compliance and highlighting the benefits of process simplification (e.g., lateral microphone placement/removal, if trusted analysis is used).
    - Provided a demonstration by assessing a simplified noise collection/analysis process.
- Developed **traceable and consistent methodology** to analyze Means of Compliance (MoC) alternatives for supporting rulemaking recommendations.
    - Model-based methods (e.g., MBSE) to **map regulatory-driven requirements to testing procedures.**
- Performed UAM noise **standards review** and **comparison with UAS standards for demarcation** of categories.
- Formulated **risk definitions and assessments**, based on various aspects of vehicle design and operational characteristics.
- Formulated **complexity-driven certification procedure modeling** using Markov Chains.
- Engaged in a **broader outreach of ASCENT Project 061** to the aviation community on noise certification, including:
    - Participation in ASCENT fall/spring meetings
    - Discussions with UAS OEMs
    - Publication of articles with AIAA and for the SciTech 2024/2025 meetings
- Provided **annual and quarterly reports**, available on the ASCENT Knowledge Services Network (KSN) database.
- Prepared peer reviewed publications for conferences, such as the AIAA SciTech 2025 and the Quiet Drones Symposium 2024.